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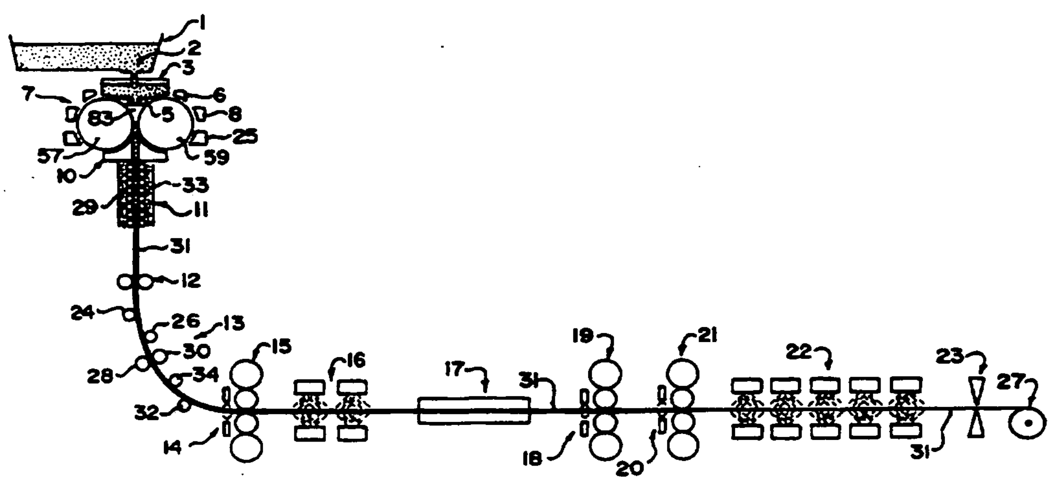
(54) Title: TWIN-ROLL CASTER AND ROLLING MILL FOR USE THEREWITH



(57) Abstract

A twin-roll caster casts steel strand of thickness preferably 5 to 35 mm. Immediately downstream of the twin rolls, a water-cooled copper stationary mold further cools the strand. The upper surfaces of the stationary mold are preferably cylindrically concave shaped to hug the twin rolls. Immediately downstream of the stationary mold, the casting passes through strand containment apparatus comprising a series of segmented rolls with secondary spray cooling. This stage is followed by a roughing stand and preferably two finishing stands; laminar flow cooling and a reheat furnace may also be used. Both a primary (e.g. 30 tons) and secondary tundish (e.g. 5 tons) are provided above the caster. An inert or reducing gaseous atmosphere is provided above the surface of the molten steel pool formed above the kissing point of the twin rolls. An elongated rectangular guiding shroud extends downwardly from the exit port of the secondary tundish, and a transversely extending splash guard extends generally horizontally outwardly from the guiding shroud at the underside of the secondary tundish. A series of offset bending and unbending rolls changes the orientation of the cast steel strand from vertical to horizontal. The bending and unbending rolls spaced on the inside of the arc of travel of the cast strand are spaced more closely together than the rolls on the outside of the arc.

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AMENDED CLAIMS

[received by the International Bureau on 27 December 1995 (27.12.95);
original claim 22 amended; new claims 53-56 added;
remaining claims unchanged (3 pages)]

17. Apparatus as defined in claim 1, wherein the stationary mold is a water-cooled copper-faced mold.

18. Apparatus as defined in claim 16, wherein the stationary mold is a water-cooled copper-faced mold.

19. Apparatus as defined in claim 1, wherein the spacing between the casting rolls at the kissing-point gap is adjustable from about 5 to about 35 mm and the dimensions of the stationary mold are adjustable to conform to those of the casting roll gap.

20. Apparatus as defined in claim 7, wherein the spacing between the casting rolls at the kissing-point gap is adjustable from about 5 to about 35 mm and the dimensions of the stationary mold are adjustable to conform to those of the casting roll gap.

21. Apparatus as defined in claim 18, wherein the spacing between the casting rolls at the kissing-point gap is adjustable from about 5 to about 35 mm and the dimensions of the stationary mold are adjustable to conform to those of the casting roll gap.

22. Apparatus as defined in claim 15, wherein the finishing reduction rolls comprise at least two 4-high finishing roll stands each comprising a pair of opposed finishing reduction rolls.

23. Apparatus as defined in claim 1, additionally comprising a heater for each of the casting rolls to preheat the surfaces of the casting rolls before they reach immediate contact with molten steel above the gap between the casting rolls, with molten steel above the gap between the casting rolls, thereby to tend to reduce thermal

twin casting rolls of the twin roll caster, the redirection rolls on the outside of the accurate path of travel of the cast steel strand being spaced apart by a greater spacing than the redirection rolls on the inside of the arcuate path of travel of the cast steel strand, said cast steel strand passing between each of said redirection roll pairs.

50. Apparatus as defined in claim 1, wherein the pool of molten steel is formed above the gap between the casting rolls and maintained in the absence of casting mold powder and in the absence of slag.

51. Apparatus as defined in claim 50, additionally comprising a lubricator for applying lubricating oil to the rotating twin roll surfaces just before they make contact with the pool of molten steel.

52. Apparatus as defined in claim 51, additionally comprising a hot-air heater for removing any water from the rotating twin roll surfaces and heating the rotating twin roll surfaces before they are lubricated by the lubricator.

53. Apparatus as defined in claim 28 wherein the stationary mold is a water-cooled mold whose faces defining said channel are made of copper.

54. Apparatus as defined in claim 53 comprising a series of reduction roll stands downstream of said strand containment apparatus for imparting hard reduction to the cast steel strip received from the strand containment apparatus.

55. Apparatus as defined in claim 36 wherein the reheat furnace includes an edge heater for heating the edges of the steel strip passing therethrough.

AMENDED SHEET (ARTICLE 19)

56. Apparatus as defined in claim 43 additionally comprising air mist cooling spray nozzles associated with the strand containment apparatus and connectable to a supply of water and air whereby a mist spray may be applied to the cast steel strip passing through the strand containment apparatus.

STATEMENT UNDER ARTICLE 19

Editorial review of the claims subsequent to filing revealed a number of areas in which claims and claim dependency relationships of record in this application did not, as intended, correspond to counterpart coverage in the parent United States application Serial No. 08/272,678. Accordingly, a few changes in the dependent claims are entered by this amendment.

Specifically, claim 22 as originally presented provides an limitation on "finishing reduction rolls"; yet in the application as originally filed, claim 22 was dependent upon claim 7. Claim 7, however, was not limited to apparatus having "finishing reduction rolls". Claim 22 has therefore been amended to depend from claim 15, which establishes a proper antecedent for "finishing reduction rolls".

Claims 53 to 56 added by this amendment correspond to claims 30, 31, 37, and 70, respectively, of the parent United States application Serial No. 08/272,678. These dependent claims were inadvertently not included in the present application as initially filed.

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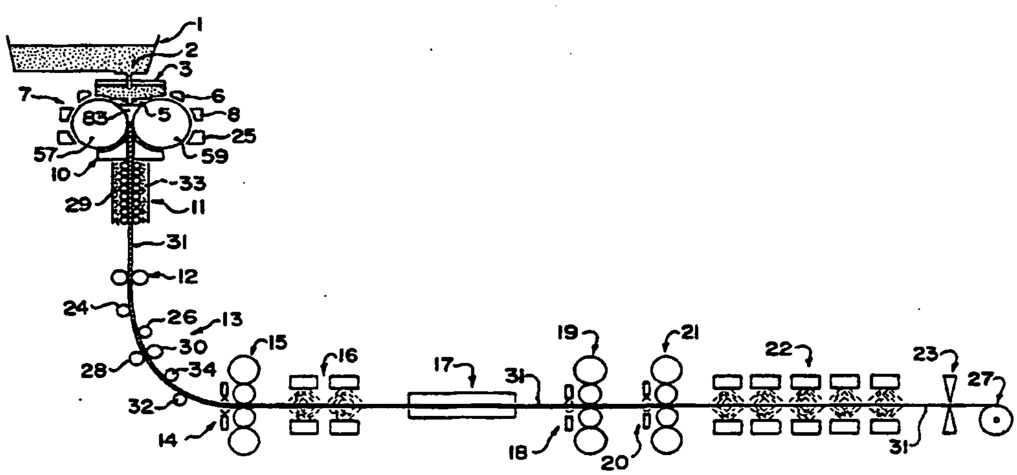

(57) Abstract

A twin-roll caster casts steel strand of thickness preferably 5 to 35 mm. Immediately downstream of the twin rolls, a water-cooled copper stationary mold further cools the strand. The upper surfaces of the stationary mold are preferably cylindrically concave shaped to hug the twin rolls. Immediately downstream of the stationary mold, the casting passes through strand containment apparatus comprising a series of segmented rolls with secondary spray cooling. This stage is followed by a roughing stand and preferably two finishing stands; laminar flow cooling and a reheat furnace may also be used. Both a primary (e.g. 30 tons) and secondary tundish (e.g. 5 tons) are provided above the caster. An inert or reducing gaseous atmosphere is provided above the surface of the molten steel pool formed above the kissing point of the twin rolls. An elongated rectangular guiding shroud extends downwardly from the exit port of the secondary tundish, and a transversely extending splash guard extends generally horizontally outwardly from the guiding shroud at the underside of the secondary tundish. A series of offset bending and unbending rolls changes the orientation of the cast steel strand from vertical to horizontal. The bending and unbending rolls spaced on the inside of the arc of travel of the cast strand are spaced more closely together than the rolls on the outside of the arc.

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TWIN-ROLL CASTER AND ROLLING MILL FOR USE THEREWITH

RELATED APPLICATIONS

This application is a counterpart of U.S. Application Serial No. 08/465,716 which is a continuation-in-part of U.S. Patent Application Serial No. 08/272,678.

FIELD OF THE INVENTION

This invention relates to a method for casting and rolling steel using twin-roll casters.

BACKGROUND; PRIOR ART

Conventionally, steel is cast in a continuous casting process by pouring the molten steel from a tundish into a mold having a rectangular cross-section that defines the width and thickness of the steel strand to be cast. The mold is typically water-cooled and is sufficiently long in extension that the outer shell of the steel solidifies sufficiently within the casting mold such that the steel retains its shape and does not burst open (break out). A caster of this sort is typically oscillated in the longitudinal (vertical) direction. Casting powder is applied so that steel will not stick to the inside walls of the casting mold, and so as to minimize radiant heat loss, and to absorb unwanted inclusions.

Downstream of the casting mold are typically arranged a series of supporting rolls for the cast strand which give it support while its core is still partly molten, thereby permitting it to continue to solidify without danger of rupture (break-out). These rolls control the exterior thickness dimension of the solid shell of the casting but typically do not reduce the dimension appreciably. In some cases, these rolls may impart a slight reduction to the

steel casting while its core is still soft or even molten, for the purpose of centerline segregation control (see, e.g., L.K. Chiang, "Application of Soft Reduction Technique for Improving Centerline Segregation in Continuously Cast Slab", 1989 Steelmaking Conference Proceedings 81).

As an alternative to a conventional caster of the foregoing sort for the continuous casting of steel slab, there may be provided for the casting of a relatively thin steel strand, a twin-roll caster. The concept of a twin-roll caster is about a century old; variants of such casters have received attention recently for the casting of very thin steel strand not intended to be further reduced from the as-cast thickness. In a twin-roll caster, a pair of identical horizontally disposed casting rolls of adequately large diameter are aligned to be axially parallel to one another, and are rotatably mounted with a slight gap between the two rolls. The width of the gap is approximately equal to the thickness of the casting to be made. The rolls rotate in opposite senses downwardly toward the narrowest part of the gap, referred to as the "kissing point". Viewed end on, the left roll rotates clockwise and the right roll counterclockwise. Molten steel is supplied from a tundish above the rolls to form a pool just above the gap between the two rolls. The molten steel solidifies as it passes towards and through the gap between the two rolls, and exits as a strand having a solid shell whose thickness is predetermined by the gap between the two casting rolls.

Such twin-roll casters are illustrated and described, for example, in Japanese published patent specification 62-77151 dated 9 April 1987, Japanese published patent specification 1-249246 dated 4 October 1989, and Japanese published patent specification 3-90261 dated 16 April 1991.

Conventionally, prior twin-roll casters have included support rolls immediately downstream of the twin casting rolls that give support to the cast strand as it leaves the twin casting rolls, and that redirect the cast strand from vertical orientation to horizontal orientation. Redirection rolls of this type are commonplace in steel making; representative such rolls are illustrated, for example, in various of the above-mentioned published Japanese specifications and are also used apart from twin-roll casters: see, *e.g.* Scholz U.S. patent 5,065,811 dated 19 November 1991.

Conventionally, in twin-roll casters such as the foregoing, only the twin casting rolls themselves constitute the means for defining the dimensions and particularly the thickness of the cast strand, and constitute the only means for cooling the molten steel sufficiently that it is sufficiently solid to avoid break-outs. However, this conventional arrangement permits the molten steel to be cooled only over a relatively short arcuate segment (typically of the order of 45°) of the periphery of the twin casting rolls with which the solidifying steel comes into contact. Conventionally, downstream of the twin casting rolls, no further special cooling arrangement is provided; consequently, downstream cooling is less rapid than cooling imparted by the twin casting rolls. Furthermore, the cast strand must be solid as it leaves the twin casting rolls, and this means that the cooling imparted by the twin casting rolls is critical. Obviously, the greater the speed of longitudinal travel of the cast steel strand, the more acute the foregoing problem. This limited contact of the cast strand with the available cooling surface of the twin casting rolls can, if higher casting speeds or the casting of thicker strand is attempted, lead to thinner shells, and to attendant increased risk of break-outs.

Furthermore, the absence in conventional apparatus and processes of downstream hard reduction implies the absence of preferred dimensional, surface and metallurgical quality of the coiled strip produced from such castings. In a conventional twin-roll caster, the upper limit on the gap between the twin casting rolls that determines the thickness of the cast strand is relatively small - typically of the order of about 1 to 5 mm. If the gap is made larger, the steel strand tends not to retain its shape, and break-outs can occur.

The advantage of conventional twin-roll casters has always appeared to be that they could cast steel of a dimension that is very small compared to the dimensions of conventional castings that are prepared using an oscillating mold of relatively large rectangular open area. Casting the steel in a thinner dimension using twin-roll casters has the advantage for some grades of steel of eliminating or minimizing the need for reduction rolling downstream of the caster, albeit with some loss of surface finish and less than optimum metallurgical quality, but with the benefit that much lower capital is required to build a steel-making facility than would be required for a conventional slab-casting and rolling mill.

It can be seen that drawbacks associated with conventional twin-roll casters include the following:

(i) Relatively low productivity, because the casting throughput is limited by the requirement that the strand be completely solid or almost so from the kissing point of the twin rolls onward. Annual production capacity of the order of a half-million tonnes is obtainable, but not much more.

(ii) Relatively low casting speed for thicker steel strand, again because of the need for solidification at the kissing point of the twin rolls. At higher speeds, the casting is not completely solid and break-outs can occur.

Bulging of the strand is also increasingly a problem as higher casting speeds are attempted.

(iii) A range of thicknesses of the cast strand insufficient to permit optimum downstream hot rolling reduction. This limitation implies that the dimensional, profile, surface and metallurgical quality of conventional twin-roll cast steel is inadequate to meet more demanding customer specifications.

SUMMARY OF THE INVENTION

I have discovered that twin-roll casting may be used to produce cast strand of a greater thickness range than is normal for twin-roll casters. A cast strand according to my invention may have extended metallurgical length that will allow the solidification of the strand to be continued at the twin-roll caster exit such that the strand retains its shape without break-out. Twin-roll casters according to my invention may be used in combination with suitable downstream reduction using an in-line hot rolling process. My apparatus can produce a finished product of superior quality relative to the product conventionally produced by twin-roll casters.

To achieve the foregoing objectives, according to one aspect of the invention, I provide a twin-roll caster that in its simplest version is of conventional design except that the gap between the twin casting rolls at the kissing point can be varied over a wider range than is usual in conventional twin-roll casting processes. The gap may be, for example, as wide as about 40 mm or as narrow as about 3 mm, but is preferably selected to be within the range about 5 to about 35 mm.

A pair of side dams preferably made of or lined with high-temperature-resistant refractory materials are

preferably employed to confine the liquid steel pool within the roll gap. The location and distance of the side dams can preferably be adjusted on-line to accommodate varying strand widths.

Immediately downstream of the twin rolls, I provide a stationary mold having a central vertical channel of rectangular cross-section through which the cast strand passes. At the point of entry of the casting into the stationary mold channel, it may lack dimensional stability and may lack sufficient shell strength that it can successfully avoid break-out of molten steel from the casting. However, the shell, in the course of passing through the stationary mold, is cooled sufficiently that the strand becomes wholly or partially solid throughout; dimensional stability is ensured by the conformation of the shell to the interior cooling faces defining the channel.

This stationary mold in a preferred embodiment is a water-cooled mold having copper cooling faces defining the central open channel structure of the mold. I use the term "copper mold" herein to mean a copper-faced mold. The mold can be of a design similar to that of conventional oscillating copper molds used in slab casters, and preferably conforms to one of the stationary mold designs to which my copending application Serial No. , filed on , is directed.

In such stationary mold, the upper surfaces are preferably concave-shaped to mate with the adjacent generally cylindrical surfaces of the twin casting rolls so that the stationary copper mold may be placed in close proximity to the twin casting rolls and immediately underneath them. The stationary copper mold is provided

with interior water channels of the type used in conventional oscillating copper molds.

Immediately downstream of the stationary mold, the cast strand in a preferred embodiment passes through strand containment apparatus comprising a series of support and cooling rolls, preferably segmented rolls, and preferably with secondary spray cooling. The cast steel strand is then driven by a pair of drive rolls through a first reduction roll station at which the thickness of the strand is reduced. The drive rolls synchronize the speed of travel of the cast steel strand between the twin-roll caster and the reduction roll station. The support and cooling rolls (strand containment apparatus) downstream of the stationary water-cooled copper mold may also be designed to impart soft reduction to the solidifying cast strand for centerline segregation control.

Depending upon space limitations, the first reduction roll station could roll the cast strand while the strand is still travelling vertically, although this is not preferred. Either before or after passing through this first reduction roll station, the orientation of the cast strand is changed from the vertical to the horizontal using appropriate redirection rolls (bending and unbending rolls to change the orientation of the cast strand). Following the first reduction, the intermediate strip is then passed through at least one and possibly two or more further in-line hot reduction roll stands, preferably finishing stands, before any final downstream operations (such as controlled cooling, shearing and down-coiling) occur.

By arranging the casting and rolling equipment and devising the processing procedure in the foregoing fashion, I am able to obtain the thin casting benefit of twin-roll casting, whilst also obtaining the benefit of dimensional

uniformity and surface finish of the casting that is typical of the product of larger oscillating mold casters. Further, because the casting is reduced in thickness at least twice and preferably three or more times before being down-coiled for shipment, the metallurgical properties of the steel strip thus produced are quite superior to those obtainable from a conventional twin-roll casting facility lacking hard reduction downstream of the caster.

Although the amount of cooling imparted by the twin casting rolls to the steel (as compared with the amount of cooling provided by the stationary mold and strand containment apparatus) will vary with apparatus and operational parameters including rotating and stationary mold temperatures and heat transfer characteristics, casting speed, strand dimensions, water temperatures and flow rates, etc., I prefer that from 5% to 10% of the strand solidification occur by reason of cooling imparted by the twin casting rolls and that the remaining 90% to 95% of solidification occur downstream of the casting rolls in the stationary mold and in the strand containment apparatus (with auxiliary spray cooling provided). All that the twin rolls need to do is to form a solid thin skin to delimit the dimensions of the cast strand; the solidification of the large majority of the mass of the cast strand should occur downstream of the twin rolls.

My invention is particularly suitable for the manufacture of steel strip of any of the following types: carbon steel, stainless steel, high-strength low alloy (HSLA) steel, and drawing-quality steel.

In a preferred embodiment of my invention, I provide further additional features, as follows:

Both a primary and secondary tundish are provided. The primary tundish is preferably equipped with flow control devices, which consist of a turbulence inhibitor at the charging area, a baffle and dam, means for providing argon injection, and a vortex killer at the discharge area to help promote inclusion flotation and separation for improving steel cleanliness. A stopper rod or slide gate regulates the liquid steel flow from primary tundish to secondary tundish. Such dual tundish arrangement is more particularly described and claimed in my copending U.S. patent application Serial No. , filed on .

A submerged entry nozzle shrouds steel flow from the primary tundish to the secondary tundish to minimize reoxidation. An inert atmosphere (argon shield) is preferably employed to displace ambient air at the joint between the primary tundish collector nozzle and the submerged entry nozzle. The submerged entry nozzle is preferably made of high-temperature-resistant refractory material.

The secondary tundish is preferably equipped with a tundish plasma heater of conventional design to improve temperature control during sequence casting. Argon is injected via a suitable gas-permeable well nozzle of the secondary tundish to generate gentle stirring and enhanced float-out of inclusions. The combined effects of plasma heating and inert gas stirring promote inclusion removal, enhance steel cleanliness, and render the molten steel temperature more homogeneous.

An inert atmosphere (argon shield) is provided to displace ambient air at the joint between the primary tundish collector nozzle and the stream guiding shroud. A reducing atmosphere is maintained in order to avoid re-oxidation by atmospheric oxygen.

As another aspect of the invention, I provide an inert or preferably a reducing gaseous atmosphere above the surface of the molten steel pool formed between the casting roll surfaces above the kissing point. This controlled gaseous atmosphere functions as a shield against the entry of oxygen and eliminates the need for casting powder or the like at the point at which molten steel flows between the casting rolls; this improves both the metallurgical quality of the steel (by eliminating the influx of oxygen) and the surface quality of the cast strand (by eliminating the casting powder, which disadvantageously can be entrained within the liquid steel).

Mixed gases comprised, for example, of 94% to 98% argon, 1% to 3% CH_4, and 1% to 3% CO_2 with total pressure slightly above one atmosphere are constantly injected into the space between the anti-splash cover and the meniscus of the liquid steel pool above the twin rolls during the casting operation. The CH_4 and CO_2 are preferably mixed in the molar ratio 1:1 and are assumed to react at 730°C. The complete reaction equilibrium within the system at 730°C yields a partial pressure of oxygen in the gases of 2.7×10^{-23} atm. Such reducing gas mixture helps to provide effective protection against the reoxidation of liquid steel.

The foregoing reducing gas mixture can also provide a gas shield (in conjunction with conventional tundish powder, if desired) for the surfaces of the liquid steel in the primary or secondary tundish, to reduce oxidation.

The foregoing controlled gas shield can be used also with other types of caster to advantage; its use is not limited to the preferred twin-roll caster herein described.

In contrast to conventional slab casting operations, the molten steel pool is neither covered by casting mold powder, nor contacted by the pouring shroud. Therefore, interactions with the atmosphere, slag, and refractories can be significantly reduced, leading to improved cleanliness of the steel.

As a further optional aspect of my invention, in combination with the inert gas shield there may be advantageously employed a guiding shroud extending downwardly from the nozzle well of the secondary tundish and a transversely extending anti-splash cover or splash guard that extends generally horizontally outwardly from the guiding shroud at the underside of the secondary tundish. The guiding shroud, of elongated rectangular cross-section in a preferred embodiment, helps to distribute the liquid steel in a smooth stream uniformly across the length of the casting rolls. The guiding shroud may be a single-nozzle or multiple-nozzle arrangement. A suitable such shroud is described in more detail in my copending U.S. patent application Serial No. , filed on .

The foregoing open-pouring guiding shroud above the molten steel pool formed above the gap in the twin-roll caster, in combination with the protective reducing gas barrier thus shields the steel flow. The shroud may be made of high-temperature resistant refractory material. The use of the steel flow guiding shroud facilitates the obtention of evenly distributed liquid steel across the pool formed above the twin-roll casting rolls, resulting in minimum penetration of the stream into the pool, which can effectively improve inclusions flotation, thus tending to reduce the entrainment of non-metallic inclusions within the solidifying shell.

A preferred splash guard extends almost to the surfaces of the casting rolls just above the pool of molten steel confined between the twin casting rolls. The splash guard prevents or at least inhibits droplets of molten steel from splashing onto the casting rolls (which splashing, if it occurred, would tend to impair the surface quality of the cast strand because of surface entrainment of metal droplets). Further, the splash guard acts as a confinement shroud for the inert gas shield. The splash guard (or anti-splash cover) also minimizes radiation heat loss, since the liquid pool is not covered by casting powder. A suitable such splash guard is described in more detail in my copending U.S. patent application Serial No. , filed on

The preferred use of a two-stage tundish arrangement itself contributes to lower stream momentum as the stream of liquid steel enters the pool above the gap between the twin casting rolls. This facilitates even flow and minimizes turbulence. These desirable effects are enhanced by the use of the preferred rectangular single-nozzle or multiple-nozzle guiding shroud. The flow rate of liquid steel is regulated by the ferrostatic height and the cross-sectional area of the guiding shroud. Note also that in the event of an emergency, flow from the primary tundish to the secondary tundish can be shut off, leaving at most the contents of the secondary tundish to cause any damage. These constituent elements of the preferred design in conjunction with the open pool above the twin casting roll gap and the use of a controlled gaseous atmosphere thereabove promote the even casting of clean steel relatively free of unwanted inclusions at a relatively even casting temperature.

A measured amount of lubricant such as rape-seed oil is preferably evenly applied to the surface of each twin

roll before such surface rotates into the pool of molten steel. Such lubricant tends to prevent sticker type break-outs of the cast strand. The use of such lubricant is especially desirable when casting thicker strands at a high casting speed. The preferred absence of casting powder indicates the use of such lubrication. Oil lubrication *per se* is previously known; it has been used for finishing roll stands.

An in-line twin-roll grinding device is preferably mounted adjacent each of the twin rolls and is used in conjunction with a crown profile gauge to ensure that the surface quality and profile of the twin rolls are kept within specifications. Such grinding device may preferably be located next to the lubricator that applies the lubricant mentioned above, so that lubricant is applied immediately after grinding.

In the vicinity of the pool of molten steel, the twin casting roll surfaces become very hot. Elsewhere in the rotary cycle of the rolls, the roll surfaces have an opportunity to cool. If the roll surfaces are too cool when they first contact the pool of molten steel, local thermal expansion of the roll surfaces may suddenly occur, which can cause distortion of the roll surfaces. To prevent unacceptable distortion of this sort, the roll surface is preferably preheated before it reaches the pool of molten steel. This may conveniently be effected according to a further optional aspect of my invention by providing a hot-air heater for each of the twin rolls in a location suitable to raise the temperature of the roll surface just before it enters the pool. Such hot-air heater may be conveniently located next to the grinder mentioned above.

Such hot-air heater is particularly valuable if water spray cooling is applied between the twin rolls and

the concave upper surfaces of the stationary mold. It is important that no water be on the roll surfaces when they make contact with the pool of molten steel.

The redirection of the cast strand from vertical to horizontal orientation requires the use of bending and unbending rolls. As a further feature of my invention, I provide a series of offset bending and unbending rolls to change the orientation of the cast steel strand from vertical to horizontal through a smooth arc of travel (at midway along the arc, I may use a pair of opposed rolls instead of offset rolls). The bending and unbending rolls spaced on the inside of the arc are spaced more closely together than the rolls on the outside of the arc. This tends to facilitate the bending and unbending with fewer rolls required to perform the operation than would be the case if conventional opposed rolls were used. One or more sets of opposed rolls can be used in conjunction with the offset rolls at the redirection station, but apart from one such pair at the midway point of the arc, I prefer to use only offset roll pairs.

According to a further aspect of my invention, I propose to impart to the cast strand, after it exits the strand containment and redirection apparatus, a substantial mechanical reduction of up to 40% immediately followed by a controlled cooling stage and immediately thereafter by a reheating stage. The controlled cooling stage reduces the temperature of the intermediate strip below the Ar_1 temperature. The reheat stage then raises the temperature of the intermediate strand to a temperature above the Ar_3 temperature, at which recrystallization occurs. The foregoing controlled processing facilitates the obtention of a preferred smaller grain size when the intermediate strip is then subsequently reduced by at least two further passes through inline reduction stages. The resulting steel

product has preferred metallurgical properties as a consequence of the foregoing processing.

A combined casting, rolling, cooling and coiling facility according to the invention can be designed that would be capable of producing annually a million tons of steel of good quality at an acceptably low cost, and in 1994 prices, would be expected to entail a capital cost of less than $100,000,000.

SUMMARY OF THE DRAWINGS

Figure 1 is a schematic elevation view, partly in section, of a preferred embodiment of the twin-roll caster, tundish arrangement and downstream rolling line embodying aspects of the present invention.

Figure 2 is a schematic layout diagram essentially identical to Figure 1, presenting a representative spacing of the sequence of constituent elements of the caster and roll line assembly, expressed in millimetres.

Figure 3 is a schematic end elevation view, partly in section, of a preferred embodiment of the primary and secondary tundishes, twin rolls and stationary mold of the cast arranged in accordance with the principles of the present invention.

Figure 4 is a schematic detailed isometric view of the elements of Figure 3 shown in preferred conjunction in accordance with the principles of the invention.

Figure 5A is a graph illustrating the thickness of cast steel strand, manufactured in accordance with the principles of the present invention, of initially cast thickness 35 mm, showing the thickness as cast and following

successive reductions as a plot of downstream distance from the top of the twin-roll caster.

Figure 5B is a graph showing the speed of travel vs. downstream distance characteristic of cast steel strand manufactured in accordance with the principles of the present invention, as cast, and following successive reductions, for an as-cast strand thickness of 35 mm, beginning from the top of the caster.

Figure 5C is a graph plotting the surface temperature, average temperature and centre-line temperature of cast steel strand of initially cast thickness 35 mm, manufactured in accordance with the principles of the present invention, varying as downstream distance from the top of the twin-roll caster through successive stages of the processing sequence according to the present invention.

Figure 6A is a graph illustrating the thickness of cast steel strand, manufactured in accordance with the principles of the present invention, of initially cast thickness 10 mm, showing the thickness as cast and following successive reductions as a plot of downstream distance from the top of the twin-roll caster.

Figure 6B is a graph showing the speed of travel vs. downstream distance characteristic of cast steel strand manufactured in accordance with the principles of the present invention, as cast, and following successive reductions, for an as-cast strand thickness of 10 mm, beginning from the top of the caster.

Figure 6C is a graph plotting the surface temperature, average temperature and centre-line temperature of cast steel strand of initially cast thickness 10 mm, manufactured in accordance with the principles of the

present invention, varying as downstream distance from the top of the twin-roll caster through successive stages of the processing sequence according to the present invention.

Figure 7A is a graph illustrating the thickness of cast steel strand, manufactured in accordance with the principles of the present invention, of initially cast thickness 5 mm, showing the thickness as cast and following successive reductions as a plot of downstream distance from the top of the twin-roll caster.

Figure 7B is a graph showing the speed of travel vs. downstream distance characteristic of cast steel strand manufactured in accordance with the principles of the present invention, as cast, and following successive reductions, for an as-cast strand thickness of 5 mm, beginning from the top of the caster.

Figure 7C is a graph plotting the surface temperature, average temperature and centre-line temperature of cast steel strand of initially cast thickness 5 mm, manufactured in accordance with the principles of the present invention, varying as downstream distance from the top of the twin-roll caster through successive stages of the processing sequence according to the present invention.

DETAILED DESCRIPTION WITH REFERENCE TO THE DRAWINGS

Molten steel is supplied from a primary tundish 1 to a secondary tundish 3 and thence via a guiding shroud 4 to form a pool of molten steel 53 just above the gap 55 formed between a pair of parallel horizontally aligned casting rolls 57, 59 rotating in opposite senses, the roll 57 rotating clockwise, and the roll 59 counterclockwise, as seen in the drawings. Framework, bearings, mountings, etc.

are omitted from the drawings for the purposes of clarity and simplicity.

The casting rolls 57 and 59 of the twin-roll caster, referred to generally by reference numeral 7, have copper peripheral cylindrical surfaces. Such twin-roll casters are well-known in the industry; a useful review can be found in the paper by Kasama *et al.*, "Twin Drum Casting Process for Stainless Steel Strand", Proceedings of SNRC-90 Conference, 14-19 October 1990, Pohang, Korea, held by The Korean Institute of Metals and The Institute of Metals, UK, at pp. 643-652. See also Cramb, "New Steel Casting Process for Thin Slab and Strand: A Historical Perspective", Iron and Steelmaker Vol. 20 No. 7, 1988, pp. 45-68. Such twin-roll casters preferably have slightly concave crown profiles in conformity with preferred practice so as to give the cast strand a slight convex profile (positive strand crown profile). The convex profile is desirable for uniform deformation of the hot strand during subsequent hot rolling reduction (see, e.g. Chiang, "Development and Application of Pass Design Models at IPSCO's Steckel Hot Strand Mill" (1992), 33rd MWSP Conference Proceedings, ISS-AIME, Vol. 29. The rolls 57, 59 may be kept within profile specifications by on-line peripheral roll grinders 8 of conventional design.

The twin-roll caster 7 casts a strand 31 ranging from about 5 mm to about 35 mm in thickness, or, less economically, sized outside these preferred dimensions to a lower limit of about 3 mm and an upper limit of about 40-50 mm. The casting 31 may preferably be about 900 to about 1800 mm in width, or somewhat outside these dimensions. This as-cast strand 31 is subsequently processed by in-line hot rolling stands (to be described below) to achieve finished strand thickness ranging from about 1.5 mm to about 12 mm, assuming the conventional 3-to-1 reduction of the

initial casting. The speed of rotation of the casting rolls 57, 59 is selected to range from about 1.5 rpm to about 12 rpm, the latter for castings of about 5 mm thickness and the former for castings of about 35 mm thickness. Cooling water flow through the rolls 57, 59 is set at about 500 GPM to 1000 GPM per roll to provide optimum cooling effect for good strand surface quality, and is adjusted according to the thickness of the casting.

Within the primary tundish 1 is a continuing supply of molten steel 61 (of, say, 30 tons within tundish 1) replenished on a steady basis from a ladle of molten steel (not shown). Although not shown in the drawings, the primary tundish 1 is preferably equipped with suitable flow control devices, which may, for example, consist of a turbulence inhibitor at the charging area, a baffle and dam, means for providing argon injection, and a vortex killer at the discharge area to help promote flotation and separation of inclusions for improving steel cleanliness. These devices are all described in my paper "Water Modelling of IPSCO's Slab Caster Tundish" published at page 437 ff. of the 1992 Steelmaking Conference Proceedings.

A stopper rod or slide gate of conventional design (not shown), e.g. the 13QC model sold by Stopinc AG, regulates the liquid steel flow from the primary tundish 1 to a secondary tundish 3. The molten steel flows from the primary tundish 1 to the secondary tundish 3 via a well exit port and associated submerged entry nozzle 2. At the joint between the primary tundish exit port and the submerged entry nozzle 2, an inert atmosphere (argon shield) is provided by means of an argon injection device 48 of conventional design. Such injection devices are used to displace any ambient air (and particularly oxygen) at the joint. The submerged entry nozzle 2 of conventional design, preferably made of high-temperature-resistant refractory

material such as high-alumina graphite, shrouds the steel flow from the primary tundish 1 to the secondary tundish 3 to reduce re-oxidation of the molten steel.

A pool 63 of molten steel within the secondary tundish 3 is continuously replenished from the primary tundish 1. The secondary tundish 3 may have, say, a capacity of five tons. The secondary tundish 3 is preferably equipped with a tundish plasma heater (not shown) of conventional design (e.g. of the type supplied by Plasma Energy Corp. and installed in the Nucor Steel plant in Norfolk, Nebraska) to improve temperature control within the range of about 5°C of target superheat temperature during sequence casting operations. For gentle stirring of the steel in the secondary tundish 3, either conventional argon stirring by means of argon injected into the well exit port 51 of the secondary tundish 3 is provided, or else induction stirring devices of the conventional type such as the EMS stirrers supplied by ABB Metallurgy may be used to generate gentle stirring of the molten steel, and to enhance the floating out of the steel of unwanted inclusions.

A guiding shroud 4 of rectangular cross-section fixed to the underside of the secondary tundish 3 and communicating with the exit port 51 of the secondary tundish 3 guides the flow of steel into the pool of molten steel 53 formed immediately above the gap 55 between twin casting rolls 57 and 59. The transverse area dimension of the guiding shroud 4 at the exit port 51 from the secondary tundish 3 is preferably about 5 mm by about 600 mm, which enables the pouring of approximately four tons per minute of liquid steel from the secondary tundish 3 into the pool 53. The guiding shroud 4 tends to isolate the incoming steel from ambient oxygen. Inert gas or a reducing gas or a combination of both is preferably injected above the pool 53

to prevent oxygen from gaining access to the surface of the molten steel pool 53.

Alternative guiding shroud structures suitable for use in the apparatus are described in detail in my copending U.S. patent application Serial No. , filed on .

An anti-splash cover or splash guard 5 is attached to the underside of the secondary tundish 3 and extends as two divided plates generally horizontally outwardly from and spaced by a short distance from the guiding shroud 4. the splash guard 5 is designed to prevent splashed metal droplets from sticking to either of the rotating twin rolls 57, 59. Such spray of droplets is often caused by the impact of the liquid steel stream on the surface of the liquid pool underneath. Another purpose of the splash guard 5 is to minimize radiation heat loss, since, in contrast to conventional designs, the liquid pool 53 is not covered by casting powder. Nor is the pool 53 in contact with a pouring nozzle or shroud. Therefore, interactions with the atmosphere, slag, and refractories can be significantly reduced, leading to improved cleanliness of the steel.

A preferred splash guard is described in more detail in my copending U.S. patent application Serial No. , filed on .

Mixed gases comprised of about 94% to 98% argon, 1% to 3% CH_4, and 1% to 3% CO_2 supplied at a total pressure slightly above one atmosphere are constantly injected into the space between the splash guard 5 and the liquid steel bath 53 during the casting operation. These gases enter the space above the pool 53 via suitable injector nozzles (not shown). They are prevented from rapidly leaving this space by the close spacing of the bent edges of the splash guard 5 to the peripheries of rolls 57, 59.

The CH_4 and CO_2 thus supplied are mixed in the molar ratio 1:1 and are assumed to react at 730°C to form CO and H_2, both reducing gases. The complete reaction equilibrium within the system at 730°C yields a calculated partial pressure of oxygen in the gases of 2.7 X 10^{-23} atm. Such a reducing gas mixture can provide effective protection against the reoxidation of liquid steel in the pool 53.

Knowing the liquid steel head (ferrostatic height) in the secondary tundish 3 and the dimensions of the kissing-point gap 55 and the well nozzle 51, from a mass balance viewpoint under steady-state conditions at a given casting speed, it is possible to design the described tundishes and associated apparatus so as to provide a certain quantity of steel 63 in the secondary tundish 3 that generates a pool of liquid steel 53 over the desired surface contact area of the twin casting rolls 57, 59. This is usually expressed as the mold-level angle A (Figure 3) subtended by the meniscus of the pool 53 and the kissing-point gap 55. This angle A should preferably be selected to lie in the range about 30° to about 45°. The flow rate of liquid steel required is governed by ferrostatic height and cross-sectional area of the guiding shroud nozzle(s).

Located between the ends of the twin casting rolls 57, 59 are side dams 83 (Figure 4) whose concave arcuate sides 85, 87 conform in shape and dimension to the cylindrical peripheries of the rolls 57, 59. The side dams 83 serve to confine the ends of the steel pool 53. The dams 83 are preferably made of high-temperature-resistant refractory material. The top edge 89 of each of the dams 83 must be above the level of the meniscus of the steel pool 53 sufficiently to prevent any overflow, and should extend as close as feasible to the splash guard 5 so as to minimize the loss of the inert gas atmosphere. The bottom edge 91 should extend below the kissing-point gap 55 to just above

the top edges of the stationary mold 10, so as to minimize the risk of any break-out between the dam 83 and the stationary mold 10. The dams 83 are designed to be movable transversely in either direction. They are illustrated in Figure 4 at the outer limit of their possible transverse movement; they may move inwardly from their positions at the ends of the rolls 57, 59 to reduce the width of the cast strand. Means (not shown), such as a suitable conventional hydraulic piston/cylinder arrangement, may be provided to adjust the spacing between the dams 83 to accommodate varying widths of strand.

Rape-seed oil or other suitable lubricant is applied to the surface of each of the twin casting rolls 57, 59 via lubricant injectors 6. The lubricant tends to minimize the risk of adherence of steel droplets to the surfaces of the casting rolls 57 and 59, and tends to prevent sticker-type breakouts of the cast strand.

As the surfaces of rolls 57, 59 rotate into contact with the pool 53 of molten steel, they become hotter. A sudden change in roll surface temperature could distort the roll surface, causing unacceptable surface variation of the cast strand 31. Further, if water spray cooling is employed in the space between the twin rolls 57, 59 and the upper concave surfaces 69 of the stationary mold 10, it will be important to remove such water from the twin rolls 57, 59. To eliminate any residual water and to prevent or mitigate such distortion, hot-air heaters 25 located adjacent the rolls 57, 59 blow hot air onto the roll surfaces before these surfaces reach the pool 53 of molten steel, raising the surface temperature of the rolls.

As the molten steel passes from the top of pool 53 to the gap 55, it begins to solidify. If the gap 55 is very narrow, say less than about 5 mm, the steel may be

completely solidified at or near the kissing point between rolls 57, 59. However, at wider gap dimensions, the still hot, liquid core of the steel as it emerges downstream of the gap 55 will not permit the strand reliably to retain its shape; absent the precautions, the risk of break-out would be high. This fact has limited the use of conventional twin-roll casters to cast strand thicknesses of less than about 5 mm.

Positioned immediately downstream and underneath of the rolls 57 and 59 is a stationary mold 10 having a central channel 65 of rectangular cross-section whose narrow dimension is approximately equal to or very slightly smaller than the dimension of the gap 55 between the twin casting rolls 57 and 59. The width of the channel 65 may taper very slightly inwardly from top to bottom to accommodate thermal contraction and solidification shrinkage of the steel strand as it solidifies; the gap width may receive fine adjustment by machining the surfaces of the stationary copper mold 10.

The stationary mold 10 is preferably a water-cooled copper mold, i.e. its faces forming the interior channel 65 are formed of copper; the balance of the mold structure may be made of steel. The mold 10 is shaped so that its upper concave surfaces 69 lie as close as possible to the casting rolls 57 and 59 above, and in particular so that the entry mouth 57 of the mold channel 65 is as close as possible to the kissing-point 55 between the casting rolls 57 and 59. The flow of mold cooling water may be adjusted so that heat flux extraction in the range of about 5 to about 30 $cal/cm^2/sec$ is obtained. This range should be satisfactory for the range of casting thicknesses for which the equipment is designed.

For the casting of very thin strands, the stationary mold 10 may not be necessary. If the strand is

solid as it leaves the twin casting rolls 57, 59, there is no need for the stationary mold 10, which can be removed and/or by-passed. However, the principal benefits of the present invention are obtained when the strand is wide enough to be cooled appreciably downstream of the casting rolls 57, 59, and when a series of reductions of such strand occur, as described below.

Cooling of the molten steel occurs over that portion of the peripheral cylindrical surface of each of the rolls 57, 59 subtended by angle A (Figure 3), and by the interior vertical faces 73 of the stationary mold 10. Further cooling occurs in a strand containment and secondary spray cooling station 11, to be further described below.

It is preferred that, at least for greater thicknesses of the cast strand, 90% or more of the solidification of the strand occur downstream of the casting rolls 57, 59. By providing most of the relatively rapid cooling required for solidification while maintaining dimensional integrity of the cast strand while its shell is still relatively thin (by using the stationary mold and strand containment and secondary spray cooling station 11 to be described) it is possible to cast strands up to about 35 mm in thickness or even somewhat more than this, the casting of steel in such thicknesses permits a series of downstream reductions to take place (to be described further below) that permit at least a 3:1 thickness reduction relative to the initial thickness of the cast strand. This enables a final strip product to be produced of thickness up to about 12 mm or more with reasonably good metallurgical properties and good surface finish.

It can be seen from the drawing that the vertical faces 73 of the stationary mold provide a cooling area that is about equal to the cooling area provided by the

cylindrical surface subtended by angle A of each of the twin casting rolls 57, 59. However, the ratio of cooling surface area of stationary mold to twin-roll caster cooling surface area, and the ratio of both to the strand containment cooling area to be described further below, may vary considerably according to the designer's preference, but I consider best results are obtained, at least for castings above 20 mm in thickness, if 90% or more of solidification of the cast strand occurs downstream of the casting rolls 57, 59. In any case, the additional provision of the stationary mold 10 to the layout can substantially increase the available primary cooling area for the steel being cast, as compared with conventional twin-roll caster design. This enables much wider gaps 55, 65 to be present between the twin rolls 57, 59 and the two opposed cooling blocks 64, 66 of the stationary caster 10 than is possible using conventional design.

For thicker castings (say 20 mm or more), end walls are preferably provided on the stationary mold to close the ends of the mold gap 65. For thinner castings (say 20 mm or less), end walls may be omitted and instead water sprays may be provided to cool the edges of the cast strand 31 as it passes through the mold gap 65.

While reference herein is made to the mold 10 as being a "stationary" mold, it is to be understood that the two opposed cooling blocks 64, 66 of the stationary mold 10 could be designated to be moved towards and away from one another to accommodate varying thicknesses of casting. The same, of course, is true for the twin rolls 57 and 59; the gap 55 may be adjusted according to the casting thickness desired. Although the apparatus according to the invention can be used for making castings with a thickness as thin as about 5 mm or even somewhat less, some of the principal advantages of the invention are most markedly obtained when

the thickness of the casting is relatively large, in about the 20 to 35 mm range or even somewhat higher.

Preferred alternative stationary mold designs are described in my copending U.S. patent application Serial No. , filed on

The caster as described may process from about 1 to about 6 tonnes of steel per minute, and the metallurgical length may vary from about zero (in which case the stationary mold may not be necessary) to about 3 m.

Immediately downstream of the stationary water-cooled copper mold 10 is a strand containment stage 11 comprising opposed pairs of horizontally rotatably mounted segmented rolls 29, one in each pair on either side of the cast strand 31 emanating from the stationary mold 10. These opposed rolls 29 are aligned with the exit port 52 of the stationary mold 10 and provide an opportunity for further cooling of the casting 31 before it reaches preferred reduction rolling temperature. The strand containment stage 11 may, for example, comprise 8 pairs of segmented rolls 29 located immediately below the extended water-cooled copper mold 10. Such segmented rolls may be of the same general type as used in conjunction with conventional oscillating slab casters.

The strand containment apparatus 11 along with the cooling surfaces of the stationary water-cooled mold 10 provide an effective metallurgical length (from the kissing point of the twin casting rolls 57, 59) of about 2100 mm for strand cast at 35 mm thickness. Equipment so designed will allow a calculated casting speed up to about 8 to 9 m/min for cast strand 35 mm thick and up to about 1 m/sec for strand 5 mm thick.

The widths of the gaps between opposed pairs of supporting rolls 29 for the strand containment apparatus 11 may be sequentially reduced, providing soft reduction for center-line segregation control. A battery of water/air mist spray nozzles 33 on either side of the roll pairs 29 provides spray cooling of the strand as it passes through the strand containment stage. The water spray may be omitted for the thinner cast strands if found to be unnecessary. The soft reduction in conjunction with the dynamic air-mist secondary spray cooling facilitates good external and internal quality of the strand. The designed heat flux removal from the secondary spray cooling is calculated to be in the range of about 10 cal/cm^2/sec to about 35 cal/cm^2/sec. The solidification constant of the cast strand is a function of spray water intensity and strand thickness. Calculated solidification constants are typically in the range of about 30 mm/$\sqrt{}$min to about 45 mm/$\sqrt{}$min for thicker cast strands.

A pair of opposed drive rolls 12 of 380 mm in diameter are located below the strand containment station 11 and just above the strand bending/unbending zone 13 (to be described) to regulate the speed of the cast steel strand 31 through subsequent stages.

The bending and unbending (redirection) zone or station 13 consists of three pairs of bending and unbending rolls (to be described) to bend and unbend the strand from a vertical position to a horizontal position. The overall bending and unbending radius of the arc of travel of the strand 31 is preferably about 3000 mm.

As few as three pair of bending and unbending rolls can be used at redirection station 13 to change the orientation of the cast steel strand from the vertical to the horizontal. An offset bending roll pair 24, 26 are

followed by an opposed roll pair 28, 30, and finally, by an offset unbending roll pair 32, 34. Note that the roll pairs 24, 26 and 32, 34 comprise offset, rather than opposed, rolls. The rolls 26, 30 and 34 that are located on the interior of the arc of travel of the steel strand 31 through the redirection station 13 are spaced more closely together than are the rolls 24, 28, 32 on the exterior of the arc of travel of the steel strand 31 through the redirection station 13. This arrangement is effective to redirect the steel strand 31 passing through the redirection station 13, with a minimum of redirection rolls being required - as few as three pair, as illustrated, can effect a smooth redirection of the steel strand 31.

It is an aspect of the invention that the cast strand 31 is preferably reduced in thickness by hard reduction to improve dimensional uniformity, surface smoothness, steel microstructure and metallurgical quality. Conventionally, a 3-to-1 reduction is desirable to achieve optimum metallurgical quality at minimum expense so as to obtain preferred physical properties of the steel. To this end, a roughing stage and subsequent finishing stages are provided according to the preference of the rolling mill designer.

In the exemplary mill layout herein described, the cast strand 31 passes first through a roughing mill 15 and then subsequently through finishing mills 19 and 21.

Depending upon space requirements, the first reduction could occur while the strand is travelling vertically, in which case the drive roll pair 12 would be replaced by a hot reduction rolling stand equipped with a conventional hydraulic descaler. However, it is conventional to change the orientation of the steel strand

from vertical to horizontal before commencing reduction, and that is the arrangement illustrated in Figure 1.

A hydraulic descale box 14 is used to descale the strand 31 prior to entering the first reduction pass through a 4-high roughing stand 15 of conventional design (except as to the width of the roll gap).

The in-line 4-high roughing stand 15 is used to roll as-cast strand with a reduction ratio of preferably about 0.3 to 0.5. The work roll and back-up roll diameters are preferably about 635/700 mm and 1925/2000 mm, respectively. The barrel length is preferably about 1925 mm. The mill drive may be equipped with 1600 horse power with a maximum roll torque of 3.5×10^5 fl-lb and a maximum roll force of 16 MN/m.

Downstream of the roughing stand 15 is a first laminar flow cooling control stage or station 16. The cooling stage 16 is designed, together with the immediately following induction furnace 17 to be described, for the purpose of achieving preferred metallurgical results. Specifically, once a significant amount of energy has imparted to the strand 31 by the roughing reduction in roughing stand 15, the laminar flow cooling station 16 reduces the temperature of the intermediate steel strip to a value below the Ar_1 temperature. Subsequently, in the induction furnace 17, the temperature of the intermediate steel strand is brought up to a level above the Ar_3 temperature. This enables recrystallization to occur in the steel. Subsequent rolling in the finishing roll stands to be described below enables a relatively fine grain structure to be achieved with suitable surface properties on the finished steel strip. Such strip is characterized by a combination of metallurgical properties that cannot be achieved by conventional twin roll casting processes.

Not only should the induction furnace 17 bring the temperature of the intermediate strip to a value above the Ar_3 temperature, but such exit temperature from the induction furnace 17 should be at or above the desired strip entry temperature at the subsequent finishing roll stands. Designed heat flux removal from laminar water flow at the station 16 is preferably in the range of about 10/cal/cm²/sec to about 35 cal/cm²/sec. The effective cooling zone is preferably about 2000 mm. This laminar flow cooling station (which is normally used in conjunction with the reheat furnace 17) may not have to be operated for the rolling of some grades of steel, but will be important in the thermomechanical rolling of high-strength steels.

The use of the inductive heating furnace 17 downstream of cooling station 16 is particularly important for thin strip production because of severe temperature drop during the earlier upstream stages. An induction edge heater (not shown) within or associated with furnace 17 can also be used to compensate for the severe temperature drop of wider strand. Input of heat flux is preferably in the range of about 10 cal/cm²/sec to 35 cal/cm²/sec. The effective reheating zone is about 3000 mm.

A second hydraulic descale box 18 is used to descale the strip 31 following its reheating by the reheat furnace/edge heater 17 and prior to entering into the first 4-high finishing roll stand 19.

The in-line 4-high finishing stand 19 rolls the strip 31 with a reduction of preferably about 0.1 to 0.3. The work roll and back-up roll diameters are preferably about 500/600 mm and 1020/1100 mm, respectively. The barrel length is preferably about 1925 mm. The mill drive may be of about 1200 hp with a maximum roll torque of about 7.5 x 10^5 fl-lb and a maximum roll force of about 10 MN/m. The

first 4-high finishing stand 19, is preferably equipped with hydraulic automatic gauge control (AGC), and work roll shifting and bending capability for strip thickness and shape control.

A hydraulic descale box 20 is used to descale the strip 31 prior to entering into a second 4-high finishing roll stand 21.

The in-line 4-high finishing stand 21 is used to impart a final finishing reduction to the strip 31, with a preferred reduction ratio of about 0.03 to 0.2. The finished strip thickness ranges from about 1 mm to about 12 mm. Work roll and back-up roll diameters for stand 21 are preferably about 500/600 mm and 1020/1100 mm respectively. The barrel length is preferably about 1925 mm. The mill drive for the finishing stand 21 may provide about 450 hp with a maximum roll torque of about 1.5×10^5 ft-lb and a maximum roll force of about 10 MN/m. The second 4-high finishing stand 21 is preferably equipped with hydraulic AGC, and work roll shifting and bending capability.

A second laminar water flow cooling station 22 downstream of the final finishing stand 21 is designed for the purpose of accelerated controlled cooling to achieve the desired downcoiler temperature. Designed heat flux removal from laminar water flow cooling is preferably in the range of about 10/cal/cm^2/sec to 40 cal/cm^2/sec. The effective cooling zone is about 5000 mm.

A conventional shear 23 and conventional downcoiler 27 terminate the rolling line. The strip after final cooling is wound up in the down-coiler 24 and then cut to length by the shear 23. Other optional equipment that might be found in a conventional rolling mill (such as edge

trimmers, etc.) are not shown for purposes of simplification, it being understood that one or more of such optional items of equipment may be provided or omitted at the discretion of the mill designer, according to the preferred practice to be followed in the mill.

An arrangement of the foregoing type should be able to produce cast strand from about 5 mm up to at least about 35 mm in thickness, and perhaps, depending upon desired properties of the final product, up to about 40 to 50 mm in thickness. For cast steel strand above about the 40 mm thickness range, the described arrangement is expected not to be as economically attractive as conventional mills that cast steel in about the 2-inch range.

At the smaller casting thicknesses, however, the present invention offers much more versatility than a conventional twin-roll caster. Because of the additional cooling provided by the stationary mold and the immediately following strand containment station, as compared with the very limited cooling afforded by a conventional twin-roll caster, the caster and associated equipment herein described permit the casting of steel strand at a high casting speed over a wide range of thicknesses, permitting downstream reduction rolling to improve dimensional, surface and metallurgical quality, and affording a relatively wide range of end product thicknesses.

The fact that the casting thickness of strand cast using the equipment and technique according to the invention is oversize relative to cast strand produced by conventional twin-roll casters means that at least two, and preferably at least three, reductions of the steel strand can and should occur downstream of the caster, thereby improving the dimensional, surface and metallurgical qualities of the finished coiled strip product (obviously

the strand could be cut to length and kept flat, but coil is the most usual product of this kind of process). It is well understood that a series of reductions in the rolling of steel plate or strand improves the microstructure and other metallurgical properties of the final product, and thus the present invention is seen to afford a higher quality of product than can be obtained using conventional twin-roll casters, with annual production of up to one million tons.

Variants on the specific layout illustrated in the drawing and described above will readily occur to those skilled in the art; the scope of the invention is as defined in the appended claims.

EXAMPLE 1

For the purposes of this example, the apparatus arrangement of Figure 1 is assumed, with the spacing and processing length of constituent elements of the apparatus dimensioned as indicated in Figure 2.

Set forth below are various specifications of the equipment that apply to the Figure 2 apparatus. The values obtained were computed using a computer simulation of the apparatus, and apply over the range of castings for which the preferred embodiment of the apparatus is designed to be used, namely castings ranging from 5 mm in thickness to 35 mm in thickness. Following these general specifications, a series of three more specific examples will be reviewed in greater detail: Example 1A, comprising equipment arranged in accordance with Example 1 set to obtain a casting thickness of 35 mm; Example 1B, for the same equipment, set to obtain a casting thickness of 10 mm; and Example 1C, for the same equipment, set to obtain a casting thickness of 5 mm.

The graphs of Figures 5A through 5C apply to the 35 mm casting (Example 1A); those of Figures 6A to 6C apply to the 10 mm casting (Example 1B), and those of Figures 7A to 7C apply to the 5 mm casting (Example 1C).

The following, then, are general specifications of the Figure 2 apparatus applicable to the range of castings from 5 to 35 mm in thickness:

Annual capacity:	0.5 to 1.0 million tons (varies with product mix)
Finished strip thickness:	1.0 to 12.0 mm (depends on casting thickness)
Product width:	about 900 to about 1830 mm
Coil weight:	about 15 to 40 metric tons
Specific coil size:	850 to 1250 PIW
Twin roll strand thickness:	5 to 35 mm
Twin roll casting speed:	8.5 to 55 m/min (depends on casting thickness)
Heat size:	100 to 150 metric tons
Steel grades:	carbon, stainless, HSLA, and drawing quality steels
Applications:	cold rolled, structural, coiled plate, and other industrial steels
Twin roll diameter:	1500 mm
Twin roll rotating speed:	1.5 to 12 rpm (depends on casting thickness)
Stationary water-cooled copper mold length:	900 mm
Mold level (Angle A):	35° to 45°
Primary cooling water flow rate:	500 to 1000 GPM
Strand containment length:	1200 mm

Support roll diameter:	100 mm
Inter-roll spacing:	130 mm
Metallurgical length (below kissing point of twin rolls):	2100 mm
Secondary spray cooling:	air-mist cooling
heat-extraction capacity	10 to 30 cal/cm^2 sec
Strand drive roll diameter:	380 mm
Bending radius:	3000 mm
Bending roll diameters:	300 to 500 mm, at designer's option
4-high roughing stand:	
Descaling:	hydraulic type
Work roll diameter:	635 to 700 mm
Work roll barrel length:	1925 mm
Back up roll diameter:	1290 mm
Back up roll barrel length:	1925 mm
Thickness reduction ratio:	0.3 to 0.5
Roll force (max.):	16 MN/m
Main drive:	1600 hp (880 kW)
Roll torque:	3.48 x 10^5 ft-lb
1st laminar cooling control:	
Length:	2000 mm
Heat-extraction capacity:	10 to 35 cal/cm^2 sec
Roller hearth furnace	
Length:	3000 mm
Heating medium:	inductive
4-high finishing rolling stands:	
Descaling:	hydraulic type
Work roll diameter:	500 to 600 mm
Work roll barrel length:	1925 mm
Back up roll diameter:	1020 mm
Back up roll barrel length:	1925 mm
Thickness reduction:	first stand: 0.2 to 0.4 second stand: 0.02 to 0.2
Additional features:	hydraulic AGC; work roll shifting and bending

Roll force:		10 MN/m
Main drive:	first stand:	1200 hp (670 kW)
	second stand:	450 hp (240 kW)
Roll torque:	first stand:	7.32×10^5 ft-lb
	second stand:	1.427×10^5 ft-lb

2nd laminar cooling control:

Length:	5000 mm
Heat flux extraction capacity:	10 to 40 cal/cm² sec

EXAMPLE 1A:

The following set of calculated values apply to a computer simulation of the casting and related processing steps illustrated in Figures 1 and 2 for a mill having the parameters given in Example 1, and with a casting thickness of 35 mm.

For this particular example, it is assumed that the tunnel furnace 17 and first laminar flow cooling unit 16 are not operating. Accordingly, the steel strand passing through these units will lose heat only through the conduction, convection and radiation losses associated with the idle condition of laminar flow unit 16 and tunnel furnace 17. The second laminar flow unit 22, however, is assumed to be operating for the purposes of this example. The following values were assumed or calculated from the computer simulation used:

Cast Steel Carbon Content,	0.04 Wt%
Liquidus Temperature, 1510°C, Solidus Temperature	1434°C

Twin-roll caster parameters:

Twin Roll Cooling Water Flow Rate,	500 GPM per roll
Mold Level (Angle A),	40°
Heat Transfer Coefficient in Water Slot,	2.42 cal/cm²/sec/°C
Overall Heat Transfer Coefficient,	0.1311 cal/cm²/sec/°C

Mold Water Temperature Difference (between entrance water temperature and exit water temperature in twin rolls), 1.745°	
Heat Flux,	190 cal/cm²/sec
Steel Thermal Conductivity,	.057 cal/cm/sec/°C
Steel Specific Heat,	0.16 cal/g/°C
Average Shell Temperature,	1000°C
Roll Rotation Speed,	11°/sec
Roll Rotation Speed,	1.817 rpm

Stationary Copper Mold and Strand Containment Parameters:

Casting Speed (m/min)	8.57
Solidifying Shell Thickness at Kissing Point (mm)	5.74
Strand Thickness (mm)	35
Heat Flux Removal by Stationary Water Cooled Copper Mold (cal/cm²/sec)	30
Heat Flux Removal by Secondary Spray Cooling (cal/cm²/sec)	30
Average Exit Strand Temperature (at exit of strand containment) (°C)	1315
Solidification Constant (mm/√min)	35.2

Roll Force Calculations for Roll Stands

Finishing	Roughing Stand	First Finishing Stand	Second Stand
Reduction Ratio	0.50	0.30	0.20
Entry Gauge (mm)	35	17.5	12.25
Exit Gauge (mm)	17.5	12.25	9.80
Average Strand Entry Temperature (°C)	1124	935	872
Average Strand Exit Temperature (°C)	1127	931	851
Entry Speed (m/min)	8.57	17.14	22.12
Exit Speed (m/min)	17.14	22.12	27.65
Angle of Roll Bite (°)	15.09	8.43	5.63
Strain Rate (1/sec)	2.14	3.35	3.70
Roll Force (MN/m)	11	9.5	7.6
Roll Force (tons)	2075	1785	1430
Power (hp)	643	487	333
Power (KW)	354	268	183
Roll Torque (ft-lb)	390,000	184,000	107,000

1st Laminar Flow Cooling Zone Heat Flux Removal
(not operating for this example)

Strand Speed (m/min)	17.14
Strand Gauge (mm)	17.5
Heat Flux Removed (cal/cm²/sec) (radiation loss only)	5.00

Average Strand Entry Temperature (°C)	1115
Average Strand Exit Temperature (°C)	1084

Inductive Edge Heater and Reheat Furnace
(not operating for this example)

Strand Speed (m/min)	17.14
Strand Gauge (mm)	17.5
Heat Flux Input (heat loss) (cal/cm^2/sec)	-5.00
Average Strand Entry Temperature (°C)	1066
Average Strand Exit Temperature (°C)	1015

2nd Laminar Flow Cooling Zone Heat Flux Removal

Strand Speed (m/min)	27.6
Strand Gauge (mm)	9.8
Heat Flux Removed (cal/cm^2/sec)	15
Average Strand Entry Temperature (°C)	836
Average Strand Exit Temperature (°C)	613
Downcoiler entry temperature (°C)	597

Referring to Figure 5A, the graph plotted shows half-strand thickness of the cast steel strand relative to the downstream distance from the top of the twin roll caster. By the time that the cast steel strand has reached point K (the kissing point of casting rolls 57, 59), the shell is of thickness 5.7 mm. By the time the strand reaches point E in the upper portion of strand containment stage 11, it has completely solidified, and its thickness has reached a stable uniform dimension, which is 35 mm for the complete strand thickness in this example, and therefore 17.5 mm for the half-strand thickness illustrated in Figure 5A. That thickness is maintained by the strand containment apparatus 11 until the cast strand reaches the first roughing stand 15 at point R along the curve of Figure 5A. At the roughing stand, it is assumed that a 50% reduction is given to the casting, and that its output thickness is 8.75 mm for the half-strand (17.5 mm for the full thickness of the strand). This dimension is maintained until the strand reaches the first finishing mill F1, where it is given a first finishing reduction and then, when it reaches the second finishing mill 21 at point F2, it is given a

second finishing reduction, reaching its final finished thickness thereafter.

As the strand is reduced in thickness, so its speed of travel increases. This fact is reflected in Figure 5B, which shows the successive increases in strand speed as the strand passes successive reductions. The speed up to the point of entry into roughing roll stand 15 is the as-cast speed that is regulated by drive rolls 12. The letters R, F1 and F2 correspond to the reduction points previously identified for Figure 5A, and show the successive speed increases of the strand as it passes through its initial roughing reduction at point R and successive finishing reductions at points F1 and F2.

In Figure 5C, temperatures at three positions of the cast steel strand are calculated to represent the thermal profile of the strand. Curve S plots the surface temperature of the steel strand; Curve A plots the average temperature through the steel strand, and Curve C plots the centre-line temperature for the steel strand. The temperatures are plotted relative to the downstream distance from the top of the twin-roll caster to the downcoiler, as is the case for the other graphs in the accompanying drawings.

The response of surface temperature S to the sequence of processing stages through which the strand passes is more pronounced (as seen in the graph of Figure 5C) than that of average temperature A or that of centre-line temperature C. Between point M at the entry point of the strand containment apparatus 11 and point P at the exit of the strand containment unit 11, the surface temperature variations imparted to the surface of the steel strand by the sequential contact of the steel strand with segmented rolls 29 and by the cooling spray 33 appear quite clearly in

Curve S. Curve S also shows the surface temperature fluctuations imparted to the cast steel strand due to effect of roll surface contact cooling as it passes through the sequence of redirection roll pairs 24, 26; 28, 30; and 32, 34. These three successive stages are represented by points B1, B2 and B3 in Figure 5C. (For the purpose of plotting curve S, the drive rolls 12 have been assumed to be disengaged. If they were engaged, an additional "blip" in the curve S would be expected to occur.) Points R, F1 and F2 on Figure 5C correspond to the points similarly labelled in Figures 5A and 5B.

EXAMPLE 1B

Example 1B is identical to Example 1A, except that instead of a 35 mm as-cast strand thickness, the thickness is set in the computer simulation at 10 mm. The computed parameters for Example 1B are as follows:

Cast Steel Carbon Content,	0.04 Wt%
Liquidus Temperature, 1510°C, Solidus Temperature	1434°C

Twin-roll caster parameters:

Twin Roll Cooling Water Flow Rate,	500 GPM per roll
Mold Level (Angle A),	40°
Heat Transfer Coefficient in Water Slot,	2.42 cal/cm²/sec/°C
Overall Heat Transfer Coefficient,	.197 cal/cm²/sec/°C
Mold Water Temperature Difference (between entrance water temperature and exit water temperature in twin rolls),	9.2°
Heat Flux,	285 cal/cm²/sec
Steel Thermal Conductivity,	.057 cal/cm/sec/°C
Steel Specific Heat,	0.16 cal/g/°C
Average Strand Shell Temperature,	1127°C
Roll Rotation Speed,	38.2°/sec
Roll Rotation Speed,	6.37 rpm

Stationary Copper Mold and Strand Containment Parameters:

Casting Speed (m/min)	30
Solidifying Shell Thickness at Kissing Point (mm)	2.8
Strand Thickness (mm)	10
Average Exit Strand Temperature (at exit of strand containment) (°C)	1244
Solidification Constant (mm/√min)	48.3

Roll Force Calculations for Roll Stands

Finishing	Roughing Stand	First Finishing Stand	Second Stand
Reduction Ratio	0.50	0.30	0.10
Entry Gauge (mm)	10.00	5.00	3.50
Exit Gauge (mm)	5.00	3.50	3.15
Average Strand Entry Temperature (°C)	1065	1036	920
Average Strand Exit Temperature (°C)	1038	979	884
Entry Speed (m/min)	30	60	85.7
Exit Speed (m/min)	60	85.7	95.2
Angle of Roll Bite (°)	7.20	4.41	2.13
Strain Rate (1/sec)	12.54	21.94	16.82
Roll Force (MN/m)	12.34	7.84	3.54
Roll Force (tons)	2324	1410	667
Power (hp)	1200	716	220.5
Power (KW)	659	394	121.3
Roll Torque (ft-lb)	261,100	77,560	19,960

1st Laminar Flow Cooling Zone Heat Flux Removal
(not operating for this example)

Strand Speed (m/min)	60
Strand Gauge (mm)	5.00
Heat Flux Removed (cal/cm²/sec) (radiation loss only)	5.00
Average Strand Entry Temperature (°C)	1024
Average Strand Exit Temperature (°C)	991

Inductive Edge Heater and Reheat Furnace

Strand Speed (m/min)	60
Strand Gauge (mm)	5.00
Heat Flux Input (cal/cm²/sec)	10.00
Average Strand Entry Temperature (°C)	975
Average Strand Exit Temperature (°C)	1041

2nd Laminar Flow Cooling Zone Heat Flux Removal

Strand Speed (m/min)	85.7
Strand Gauge (mm)	3.15
Heat Flux Removed (cal/cm²/sec)	20
Average Strand Entry Temperature (°C)	884
Average Strand Exit Temperature (°C)	582
Downcoiler entry temperature (°C)	566

The graphs of Figures 6A, 6B and 6C are to be understood in exactly the same way as the graphs of Figures

Figures 5A, 5B and 5C, except that the strand thickness as cast for Figures 6A, 6B and 6C is 10 mm instead of 35 mm for Figures 5A, 5B and 5C.

There is one significant difference between Examples 1A and 1B, namely the fact that for the 10 mm as-cast steel strand, the tunnel furnace 17 is operated, whereas it was not operated for the 35 mm example 1A. This difference is graphically illustrated in Figure 6C, which shows a gradual temperature increase beginning at point T when the strand reaches the entry port of the tunnel furnace 17.

EXAMPLE 1C

Example 1C is identical to Example 1B, except that instead of a 10 mm as-cast strand thickness, the thickness is set in the computer simulation at 5 mm. The computed parameters for Example 1C are as follows:

Cast Steel Carbon Content,	0.04 Wt%
Liquidus Temperature, 1510°C, Solidus Temperature	1434°C

Twin-roll caster parameters:

Twin Roll Cooling Water Flow Rate,	500 GPM per roll
Mold Level (Angle A),	40°
Heat Transfer Coefficient in Water Slot,	2.42 cal/cm²/sec/°C
Overall Heat Transfer Coefficient,	.197 cal/cm²/sec/°C
Mold Water Temperature Difference (between entrance water temperature and exit water temperature in twin rolls),	19.6°
Heat Flux,	335 cal/cm²/sec
Steel Thermal Conductivity,	.057 cal/cm/sec/°C
Steel Specific Heat,	0.16 cal/g/°C
Average Strand Shell Temperature,	1192°C
Roll Rotation Speed,	69.5°/sec
Roll Rotation Speed,	11.6 rpm

Stationary Copper Mold and Strand Containment Parameters:

Casting Speed (m/min)	54.5
Solidifying Shell Thickness at Kissing Point (mm)	1.93
Strand Thickness (mm)	5
Heat Flux Removal by Stationary Water	

Cooled Copper Mold (cal/cm^2/sec)	30
Heat Flux Removal by Secondary Spray Cooling (cal/cm^2/sec)	30
Average Exit Strand Temperature (at exit of strand containment) (°C)	1173
Solidification Constant (mm/$\sqrt{}$min)	83.7

Roll Force Calculations for Roll Stands

	Roughing Stand	First Finishing Stand	Second Finishing Stand
Reduction Ratio	0.50	0.30	0.10
Entry Gauge (mm)	5.00	2.50	1.75
Exit Gauge (mm)	2.50	1.75	1.58
Average Strand Entry Temperature (°C)	951	920	788
Average Strand Exit Temperature (°C)	944	914	820
Entry Speed (m/min)	54.5	109.1	155.9
Exit Speed (m/min)			
Angle of Roll Bite (°)	5.09	3.12	1.51
Strain Rate (1/sec)	32.3	56.5	43.3
Roll Force (MN/m)	13.12	7.5	3.67
Roll Force (tons)	2471	1413	691
Power (hp)	1636	923	294
Power (KW)	900	508	161.6
Roll Torque (ft-lb)	196,300	54,960	14,610

1st Laminar Flow Cooling Zone Heat Flux Removal
(not operating for this example)

Strand Speed (m/min)	109.1
Strand Gauge (mm)	2.50
Heat Flux Removed (cal/cm^2/sec) (radiation loss only)	5.00
Average Strand Entry Temperature (°C)	930
Average Strand Exit Temperature (°C)	897

Inductive Edge Heater and Reheat Furnace

Strand Speed (m/min)	109.1
Strand Gauge (mm)	2.50
Heat Flux Input (cal/cm^2/sec)	15
Average Strand Entry Temperature (°C)	880
Average Strand Exit Temperature (°C)	1038

2nd Laminar Flow Cooling Zone Heat Flux Removal

Strand Speed (m/min)	109.1
Strand Gauge (mm)	1.58
Heat Flux Removed (cal/cm^2/sec)	10
Average Strand Entry Temperature (°C)	805

Average Strand Exit Temperature (°C)	660
Downcoiler entry temperature (°C)	646

The graphs of Figures 7A, 7B and 7C are to be understood in exactly the same way as the graphs of Figures 6A, 6B and 6C, except that the strand thickness as cast for Figures 6A, 6B and 6C is 5 mm instead of 10 mm for Figures 6A, 6B and 6C.

In the foregoing discussion, I have used the terms "strand" and "strip" to a certain extent interchangeably. The steel as cast is a properly finished product ready for shipment, it is a "strip". In between, it is an intermediate strip product that I have sometimes referred to as a strand, sometimes as a strip.

I CLAIM:

1. In or for use with a mill for producing a steel strand from a supply of molten steel, casting and rolling apparatus comprising

a twin-roll caster having two generally horizontally disposed mating parallel twin casting rolls rotatably mounted and separated by a gap that is a minimum of about 3 millimetres and is a maximum of about 50 millimetres in width, into which gap molten steel is transferred by the combined effects of gravity and the rotation in opposite downward senses of the two twin casting rolls thereby to form a cast steel strand;

a stationary mold having an open generally vertical channel of rectangular cross-section whose dimensions conform to the dimensions of the cast steel strand and whose mouth is located immediately downstream of and in alignment with the kissing point between the twin casting rolls, which stationary mold receives the cast steel strand from the twin casting rolls and cools said strand as the strand passes through the channel; and

strand containment apparatus having a series of opposed generally horizontally disposed and vertically aligned water-cooled strand containment rolls immediately downstream of the exit of the stationary mold and aligned therewith, for receiving and cooling the cast steel strand as the strand passes between the strand containment rolls.

2. Apparatus as defined in claim 1, additionally comprising redirection means in line with the caster for redirecting the cast steel strand after it exits the stationary mold from a substantially vertical orientation to generally horizontal orientation.

3. Apparatus as defined in claim 2, wherein the redirection means comprises a series of bending and unbending rolls between which the cast steel strand passes.

4. Apparatus as defined in claim 3, wherein the redirection means is located immediately downstream of the strand containment rolls.

5. Apparatus as defined in claim 1, additionally comprising in-line reduction rolling means downstream of the strand containment rolls for reducing the thickness of the cast strand after it has solidified.

6. Apparatus as defined in claim 5, additionally comprising redirection means in line with the caster for redirecting the cast steel strand after it exits the stationary mold from a substantially vertical orientation to generally horizontal orientation.

7. Apparatus as defined in claim 6, wherein the reduction rolling means is located downstream of and in line with the redirection means.

8. Apparatus as defined in claim 1, wherein the spacing between the casting rolls at the kissing point is adjustable from about 5 to about 35 mm.

9. Apparatus as defined in claim 8, additionally comprising redirection means in line with the caster for redirecting the cast steel strand after it exits the stationary mold from a substantially vertical orientation to generally horizontal orientation.

10. Apparatus as defined in claim 9, wherein the redirection means comprises a series of bending and unbending rolls between which the cast steel strand passes.

11. Apparatus as defined in claim 10, wherein the redirection means is located immediately downstream of the strand containment rolls.

12. Apparatus as defined in claim 8, additionally comprising in-line reduction rolling means downstream of the strand containment rolls for reducing the thickness of the casting after it has solidified.

13. Apparatus as defined in claim 12, additionally comprising redirection means in line with the caster for redirecting the cast steel strand after it exits the stationary mold from a substantially vertical orientation to generally horizontal orientation.

14. Apparatus as defined in claim 13, wherein the reduction rolling means is located downstream of and in line with the redirection means.

15. Apparatus as defined in claim 1, wherein said reduction rolling means includes a pair of opposed roughing reduction rolls downstream of the mold for reduction rolling of the strand while the strand travels substantially vertically, and at least one further pair of opposed finishing reduction rolls for further reduction rolling of the strand after its orientation has become substantially horizontal.

16. Apparatus as defined in claim 14, wherein said reduction rolling means includes a pair of opposed roughing reduction rolls downstream of the mold for reduction rolling of the strand while the casting travels substantially vertically, and at least one further pair of opposed finishing reduction rolls for reduction rolling of the strand after its orientation has become substantially horizontal.

17. Apparatus as defined in claim 1, wherein the stationary mold is a water-cooled copper-faced mold.

18. Apparatus as defined in claim 16, wherein the stationary mold is a water-cooled copper-faced mold.

19. Apparatus as defined in claim 1, wherein the spacing between the casting rolls at the kissing-point gap is adjustable from about 5 to about 35 mm and the dimensions of the stationary mold are adjustable to conform to those of the casting roll gap.

20. Apparatus as defined in claim 7, wherein the spacing between the casting rolls at the kissing-point gap is adjustable from about 5 to about 35 mm and the dimensions of the stationary mold are adjustable to conform to those of the casting roll gap.

21. Apparatus as defined in claim 18, wherein the spacing between the casting rolls at the kissing-point gap is adjustable from about 5 to about 35 mm and the dimensions of the stationary mold are adjustable to conform to those of the casting roll gap.

22. Apparatus as defined in claim 7, wherein the finishing reduction rolls comprise at least two 4-high finishing roll stands each comprising a pair of opposed finishing reduction rolls.

23. Apparatus as defined in claim 1, additionally comprising a heater for each of the casting rolls to preheat the surfaces of the casting rolls before they reach immediate contact with molten steel above the gap between the casting rolls, with molten steel above the gap between the casting rolls, thereby to tend to reduce thermal

distortion of the surfaces of the casting rolls when they reach immediate contact with the molten steel.

24. Apparatus as defined in claim 1, additionally comprising cooling spray nozzles associated with the strand containment apparatus and connectable to a supply of water whereby water spray may be applied to the cast steel strand passing through the strand containment apparatus.

25. Apparatus as defined in claim 24, wherein the oppositely disposed containment rolls in the respective columns of the strand containment apparatus are spaced apart by a converging spacing from top to bottom of the strand containment apparatus thereby to impart soft reduction to the strand passing therebetween.

26. Apparatus as defined in claim 25, wherein the gap between the twin casting rolls, the stationary mold and the uppermost of the support rolls of the strand containment apparatus is adjustable between about 5 mm and about 35 mm.

27. Apparatus as defined in claim 26, additionally comprising a splash guard interposed between the underside of the secondary tundish and the exposed surface of the pool of steel formed between the twin casting rolls above the kissing point thereof, for inhibiting the splashing of the cylindrical surfaces of the twin casting rolls by molten steel poured from the secondary tundish into the pool of steel above the kissing point of the twin casting rolls.

28. Apparatus as defined in claim 27, additionally comprising means connected to a supply of gas to provide a controlled gaseous atmosphere above the exposed surface of the pool of molten steel above the kissing point of the twin casting rolls.

29. Apparatus as defined in claim 1, additionally comprising a lubricator for each of the casting rolls for applying lubricant to the surfaces of the casting rolls.

30. Apparatus as defined in claim 1, wherein the twin casting rolls cast a strand whose shell is solid but whose interior is liquid prior to entering the stationary mold.

31. Apparatus as defined in claim 30, wherein, when the apparatus is in use, the strand is about 90% or more liquid when it enters the stationary mold.

32. In combination, a twin-roll caster having a gap between twin casting rolls thereof adjustable between about 5 mm and about 35 mm;

a water-cooled copper-faced stationary mold located immediately downstream of and in alignment with the kissing point of the twin casting rolls and having a generally central open channel of rectangular cross-section adjustable to conform to the dimensions of the cast steel strand emanating from the kissing point between the twin casting rolls;

strand containment apparatus comprising a vertically disposed sequential array of paired spaced support and cooling rolls mating and aligned with and immediately downstream of the stationary mold;, the spacing between the sequence of spaced support and cooling rolls in the strand containment means being adjustable to conform to the dimensions of the cast steel strand emanating from the stationary mold channel;

a set of in-line redirection rolls for receiving the cast steel strand from the strand containment apparatus and bending and unbending the cast steel strand so as to change its orientation from a substantially vertical orientation to a substantially horizontal orientation; and

a series of in-line reduction roll stands for receiving in sequence the steel strand from the redirection rolls and imparting hard reduction to the cast steel strand.

33. Apparatus as defined in claim 32, wherein the upper surfaces of the stationary mold are generally concave-shaped to conform to the cylindrical surfaces of the adjacent twin casting rolls, said concave surfaces being closely spaced from the adjacent twin casting rolls.

34. Apparatus as defined in claim 32 wherein the set of redirection rolls comprises a central pair of opposed rolls, a pair of offset rolls located upstream of the opposed rolls, and a pair of offset rolls located downstream of the opposed rolls, all of the rolls of the redirection apparatus being rotatably mounted on axes of rotation generally parallel to the axes of rotation of the twin casting rolls, the redirection rolls on the outside of the arcuate path of travel of the cast steel strand being spaced apart by a greater spacing than the redirection rolls on the inside of the arcuate path of travel of the cast steel strand, said cast steel strand passing between each of said redirection roll pairs.

35. Apparatus as defined in claim 32 wherein said reduction rolls comprise a roughing roll stand located downstream of the redirection apparatus and a first and second finishing roll stand sequentially located downstream of the roughing roll stand.

36. Apparatus as defined in claim 35 additionally comprising a first laminar flow cooling unit followed by a reheat furnace, said first laminar flow cooling unit and reheat furnace being located between the roughing roll stand and the first finishing roll stand and in line therewith for

receiving the steel strand after roughing reduction thereof, for adjusting and controlling the temperature thereof.

37. Apparatus as defined in claim 36, wherein the laminar flow cooling unit cools the rough-reduced strand to a temperature below the Ar_1, and the reheat furnace heats the strand to a temperature above the Ar_3.

38. Apparatus as defined in claim 36, additionally comprising a second laminar flow cooling apparatus downstream of and in line with the second finishing roll stand.

39. Apparatus as defined in claim 2, wherein the vertical extension of the stationary mold is selected to cool the cast steel strand passing therethrough sufficiently to enable the cast steel strand to achieve dimensional and surface stability without break-out or bulging by the time it exits the stationary mold.

40. Apparatus as defined in claim 14, wherein the strand containment apparatus additionally comprises cooling spray nozzles connectable to a supply of water for providing water spray to the cast steel strand passing through the strand containment apparatus.

41. Apparatus as defined in claim 12, additionally comprising a generally horizontally disposed splash guard positioned immediately above the pool of molten steel formed above the kissing point of the twin rolls of the twin-roll caster for inhibiting the splashing of molten droplets of steel onto the cylindrical casting surfaces of the twin casting rolls.

42. In or for use with a mill for producing steel strand from a supply of molten steel, casting and rolling apparatus comprising

a twin-roll caster having two generally horizontally disposed mating parallel twin casting rolls rotatably mounted and separated by a gap that is a minimum of about 3 millimetres and is a maximum of about 50 millimetres in width, into which gap molten steel is transferred by the combined effects of gravity and the rotation in opposite downward senses of the two horizontally disposed parallel rolls of the twin-roll caster thereby to form a cast steel strand;

a stationary mold having an open generally vertical channel of rectangular cross-section whose dimensions conform to the dimensions of the steel strand and whose mouth is located immediately downstream of the kissing point between the two rolls of the twin-roll caster, which stationary mold receives the steel strand from the twin casting rolls and cools said strand as the strand passes through the channel;

means for redirecting the strand after it exits from the stationary mold from a substantially vertical orientation to horizontal or near horizontal orientation; and

reduction rolling means for reducing the thickness of the strand after it has substantially achieved dimensional and surface stability.

43. Apparatus as defined in claim 42, wherein the spacing between the casting rolls at the kissing point is adjustable from about 5 to about 35 mm.

44. Apparatus as defined in claim 42, wherein said reduction rolling means includes a pair of opposed roughing reduction rolls downstream of the mold for reduction rolling of the strand while the strand travels substantially

vertically, and at least one further pair of opposed finishing reduction rolls for reduction rolling of the strand after its orientation has become substantially horizontal.

45. Apparatus as defined in claim 42, wherein the stationary mold is a water-cooled copper-faced mold.

46. Apparatus as defined in claim 45, wherein the spacing between the casting rolls at the kissing-point gap is adjustable from about 5 to about 35 mm and the dimensions of the stationary mold are adjustable to conform to those of the casting roll gap.

47. Apparatus as defined in claim 44, wherein the finishing reduction rolls comprise at least two 4-high finishing roll stands each comprising a pair of opposed finishing reduction rolls.

48. Apparatus as defined in claim 47, wherein the vertical extension of the channel in the stationary mold and the vertical extension of the strand containment apparatus are selected to be of sufficient length that the cast steel strand has completely solidified before it has reached the midpoint in a vertical sense of the strand containment apparatus.

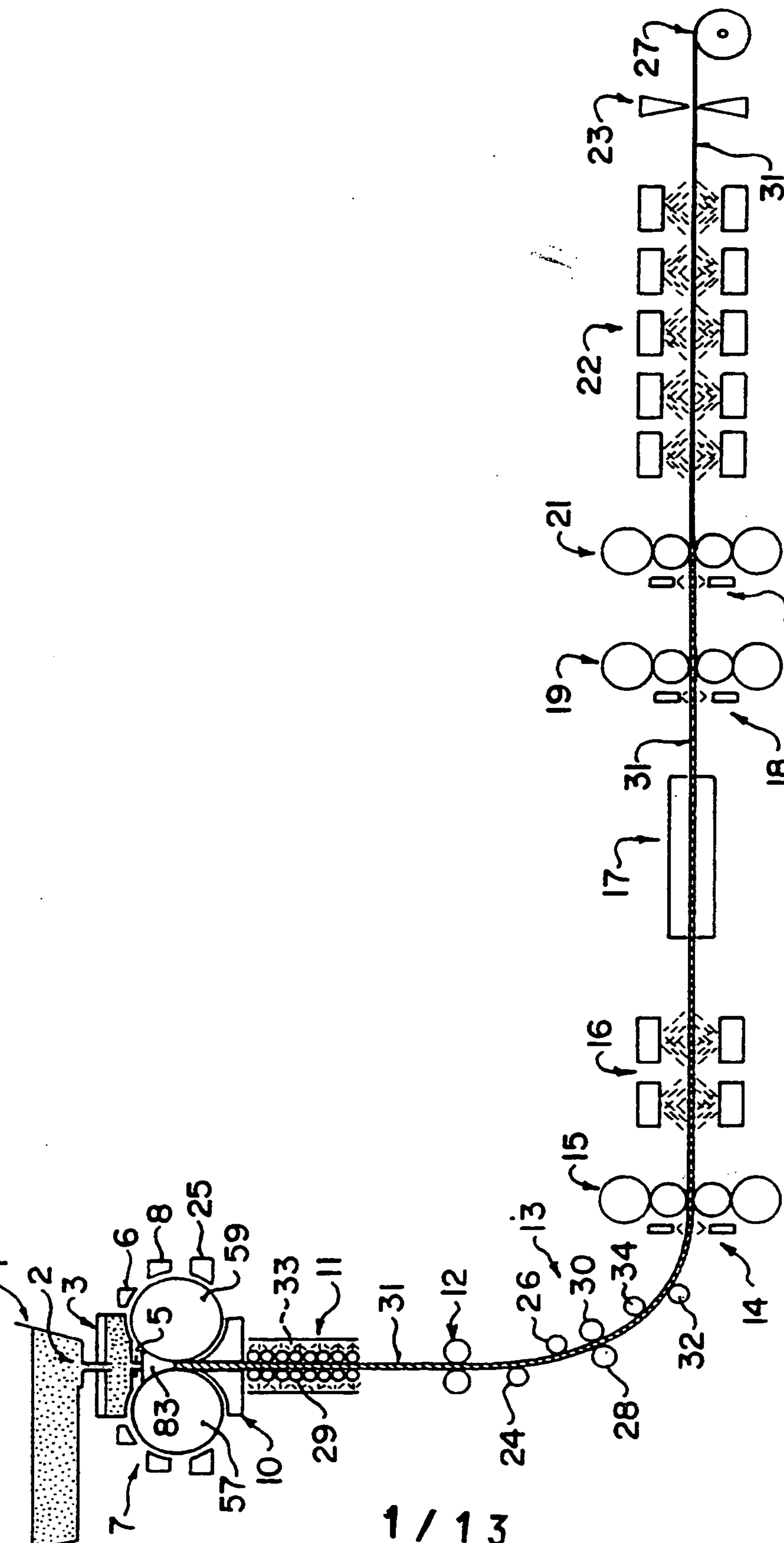
49. In or for use with a twin roll caster, redirection apparatus for redirecting a cast strand from substantially vertical to substantially horizontal orientation, comprising a set of redirection rolls including a central pair of opposed rolls, a pair of offset rolls located upstream of the opposed rolls, and a pair of offset rolls located downstream of the opposed rolls, all of the rolls of the redirection apparatus being rotatably mounted on axes of rotation generally parallel to the axes of rotation of the

twin casting rolls of the twin roll caster, the redirection rolls on the outside of the accurate path of travel of the cast steel strand being spaced apart by a greater spacing than the redirection rolls on the inside of the arcuate path of travel of the cast steel strand, said cast steel strand passing between each of said redirection roll pairs.

50. Apparatus as defined in claim 1, wherein the pool of molten steel is formed above the gap between the casting rolls and maintained in the absence of casting mold powder and in the absence of slag.

51. Apparatus as defined in claim 50, additionally comprising a lubricator for applying lubricating oil to the rotating twin roll surfaces just before they make contact with the pool of molten steel.

52. Apparatus as defined in claim 51, additionally comprising a hot-air heater for removing any water from the rotating twin roll surfaces and heating the rotating twin roll surfaces before they are lubricated by the lubricator.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17
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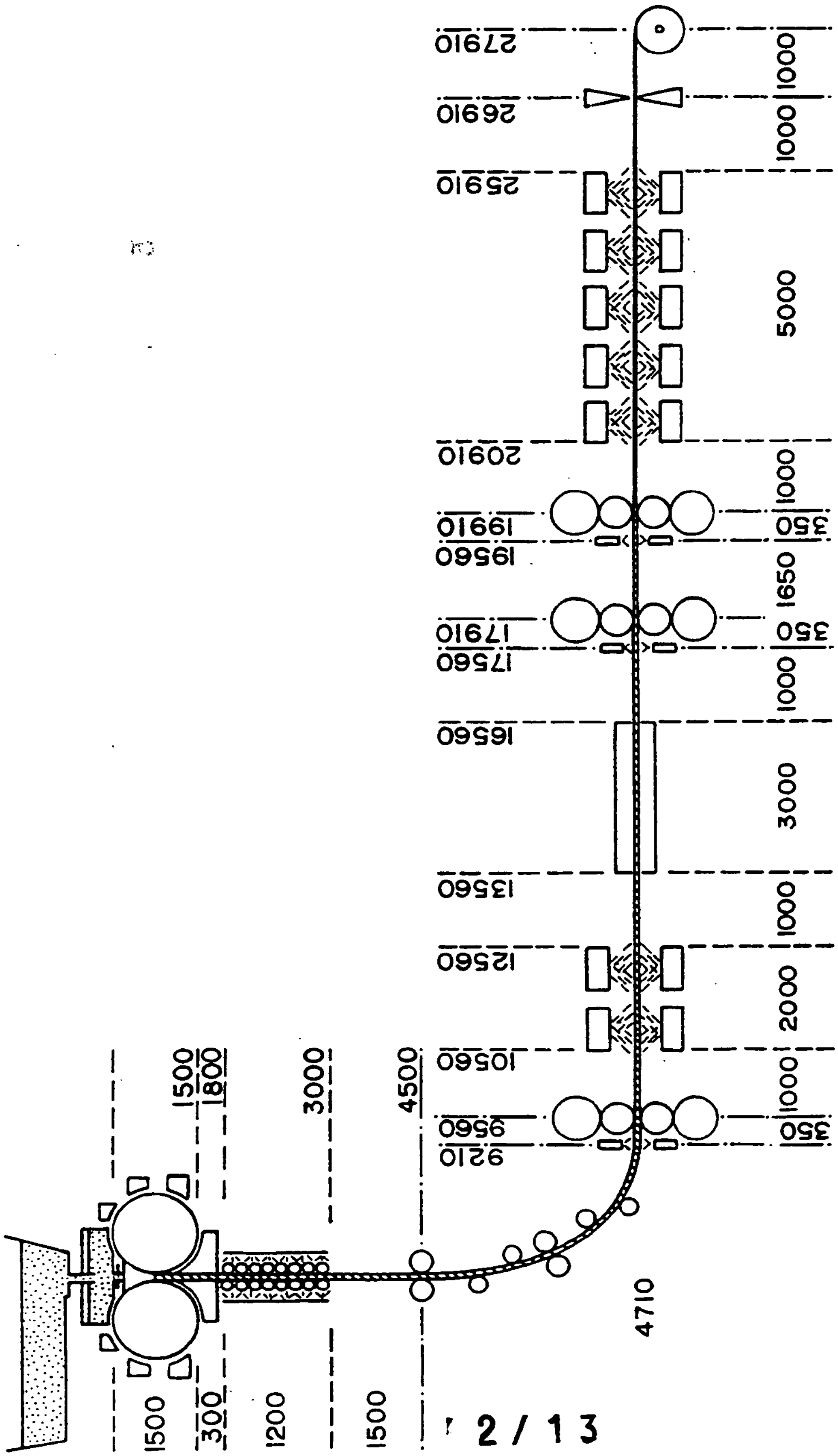
25
26
27
28
29
30
31
32
33
34
57
59
83

FIG. 1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17910
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9560
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5000
1000
350
1650
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1000
3000
1000
2000
1000
350
4710
1500
1800
3000
4500
1500
300
1200
1500

FIG. 2

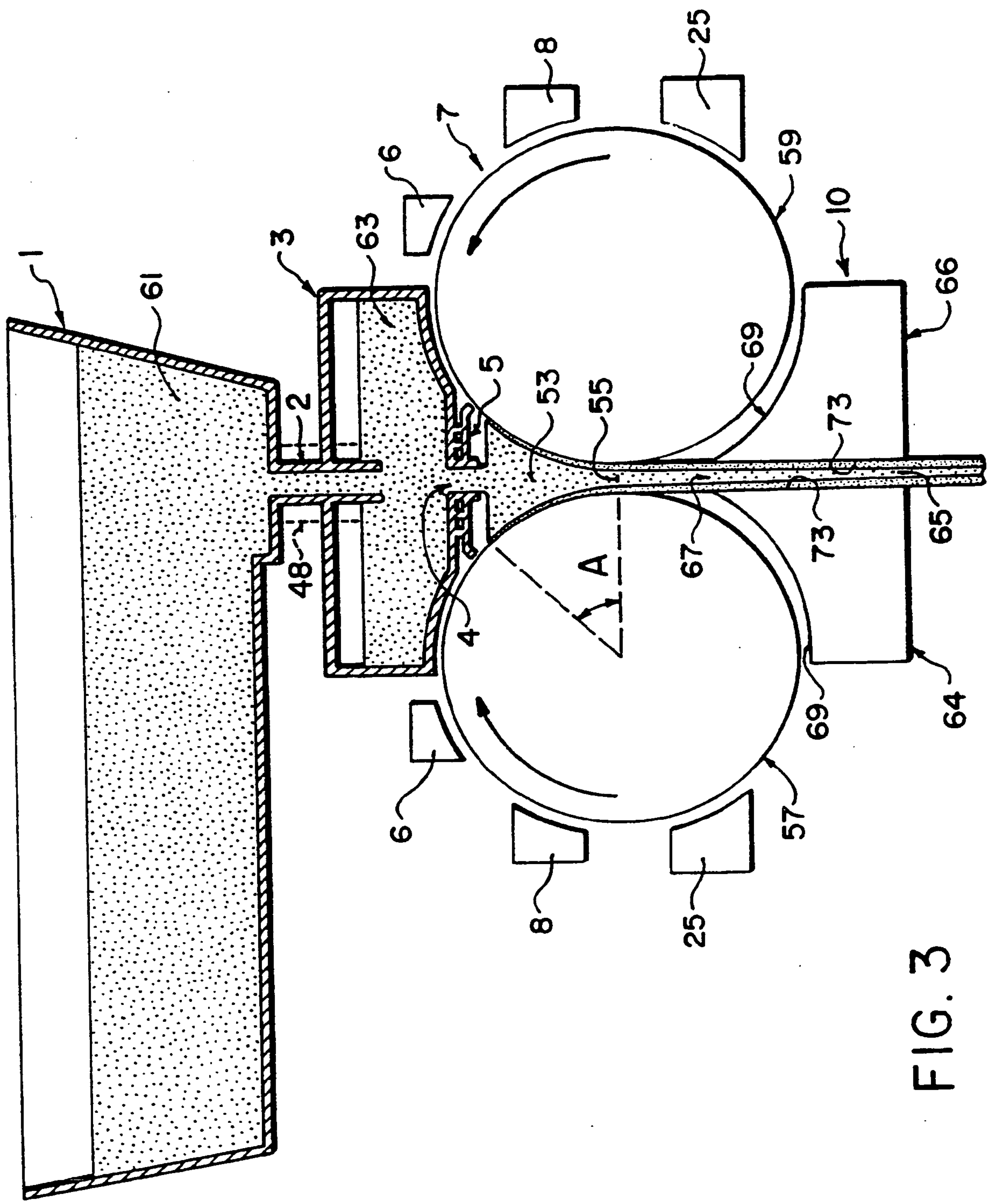

FIG. 3

SUBSTITUTE SHEET

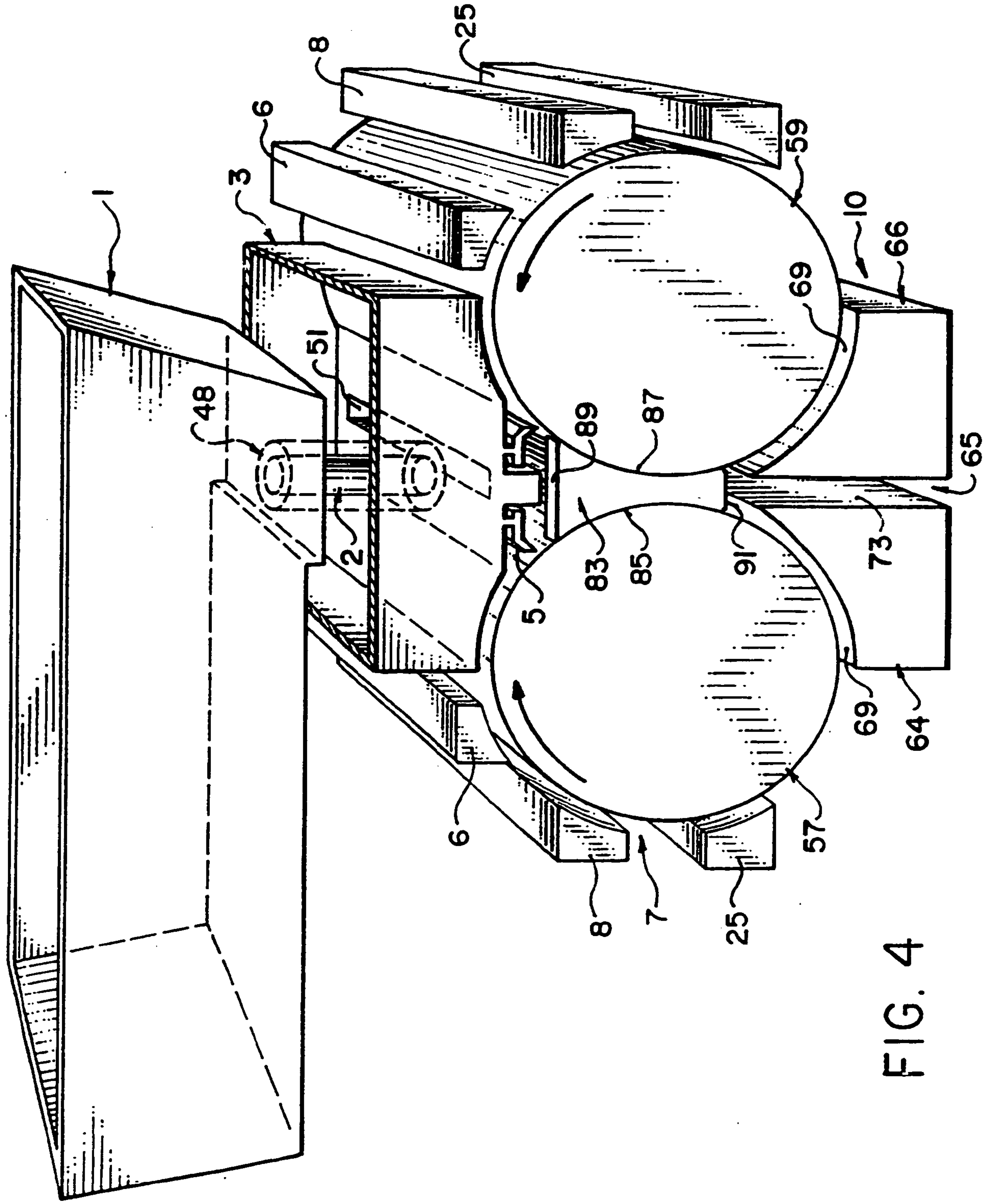

FIG. 4

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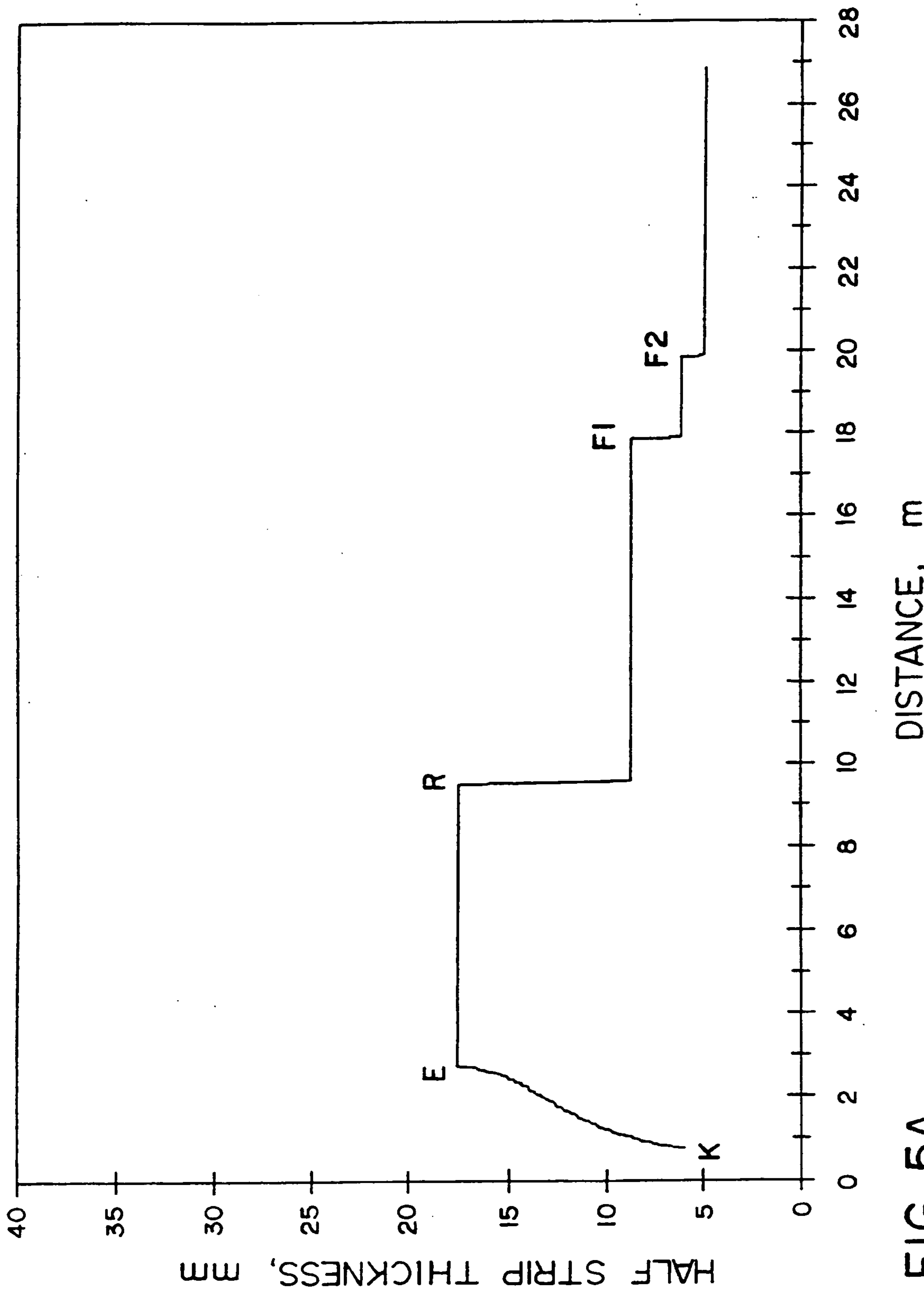
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DISTANCE, m
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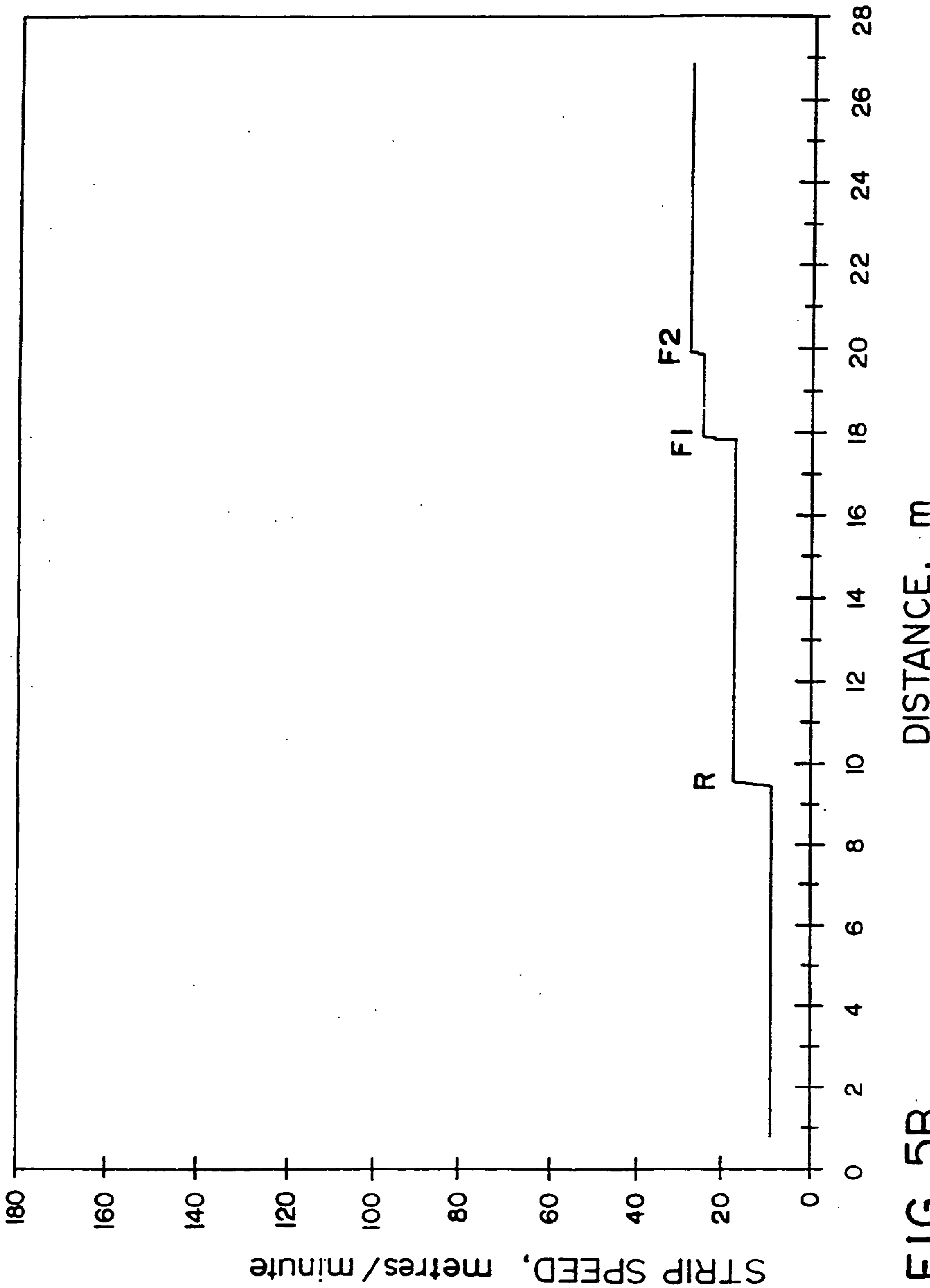
E
R
FI
F2
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28

FIG. 5A


STRIP SPEED, metres/minute
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20
40
60
80
100
120
140
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180
DISTANCE, m
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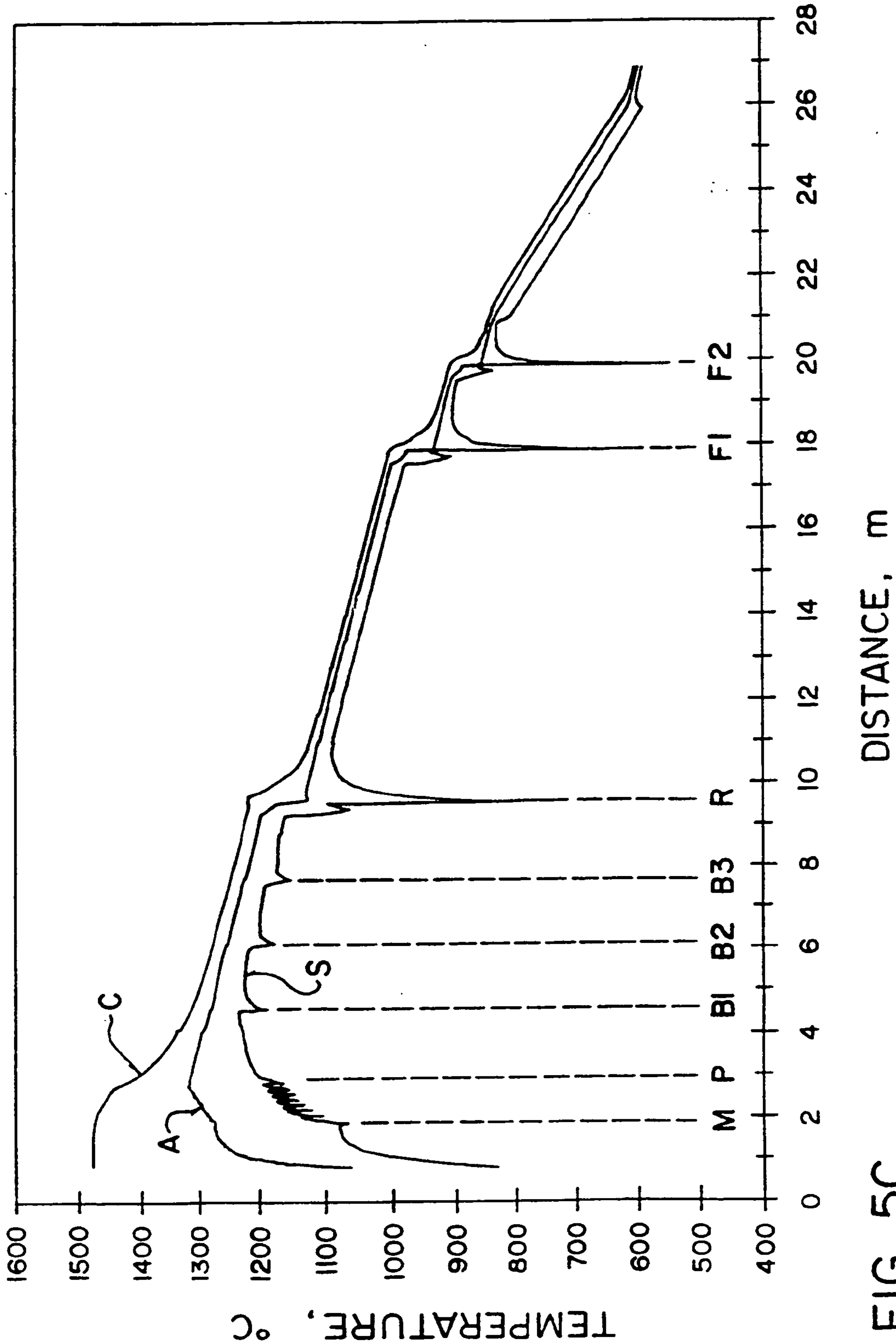
10
12
14
16
18
20
22
24
26
28
R
F1
F2

FIG. 5B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1400
1300
1200
1100
1000
900
800
700
600
500
400
DISTANCE, m
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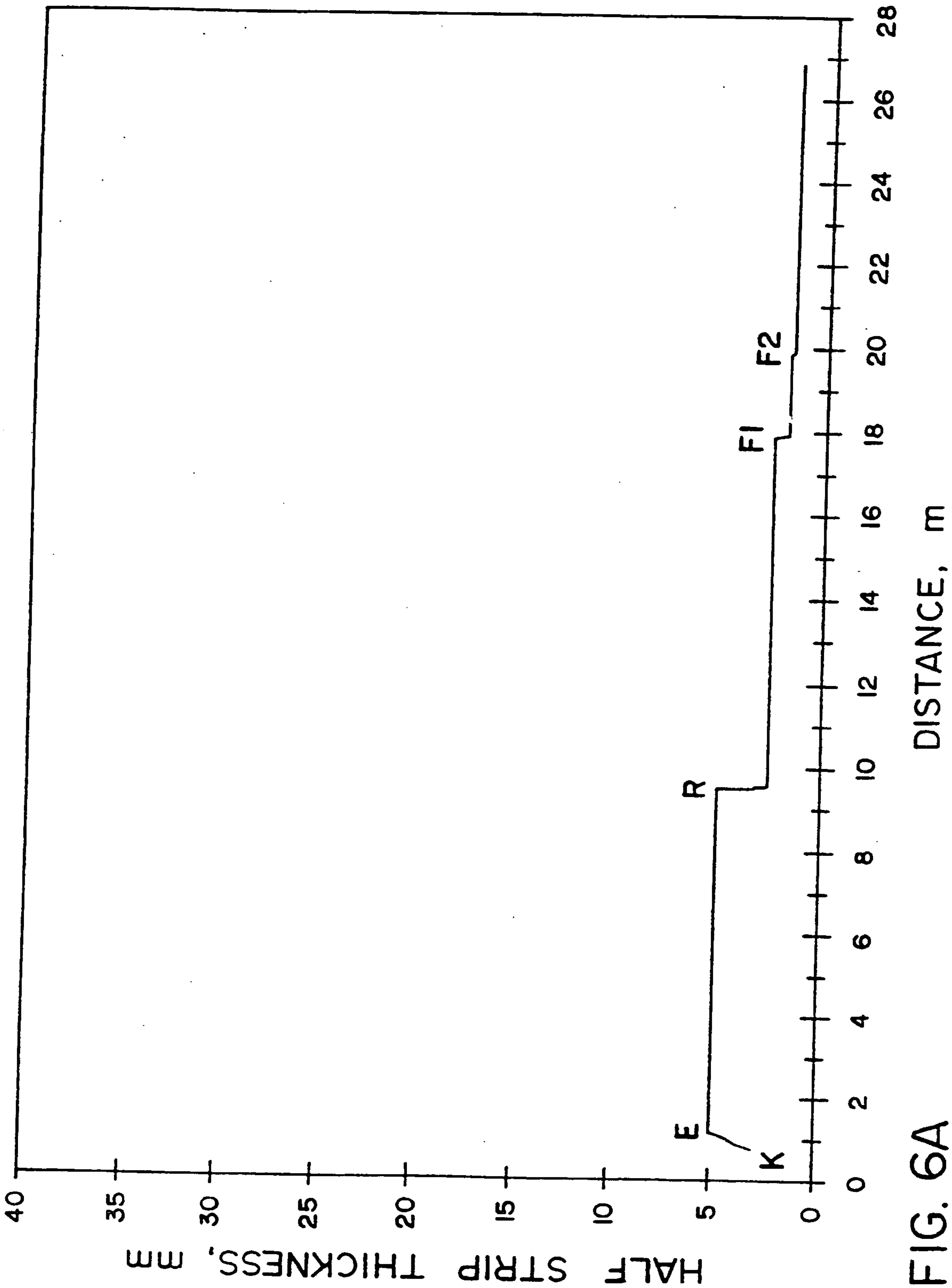
2
4
6
8
10
12
14
16
18
20
22
24
26
28
C
A
S
M
P
BI
B2
B3
R
FI
F2

FIG. 5C


HALF STRIP THICKNESS, mm
DISTANCE, m
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15
20
25
30
35
40
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
K
E
R
F1
F2

FIG. 6A

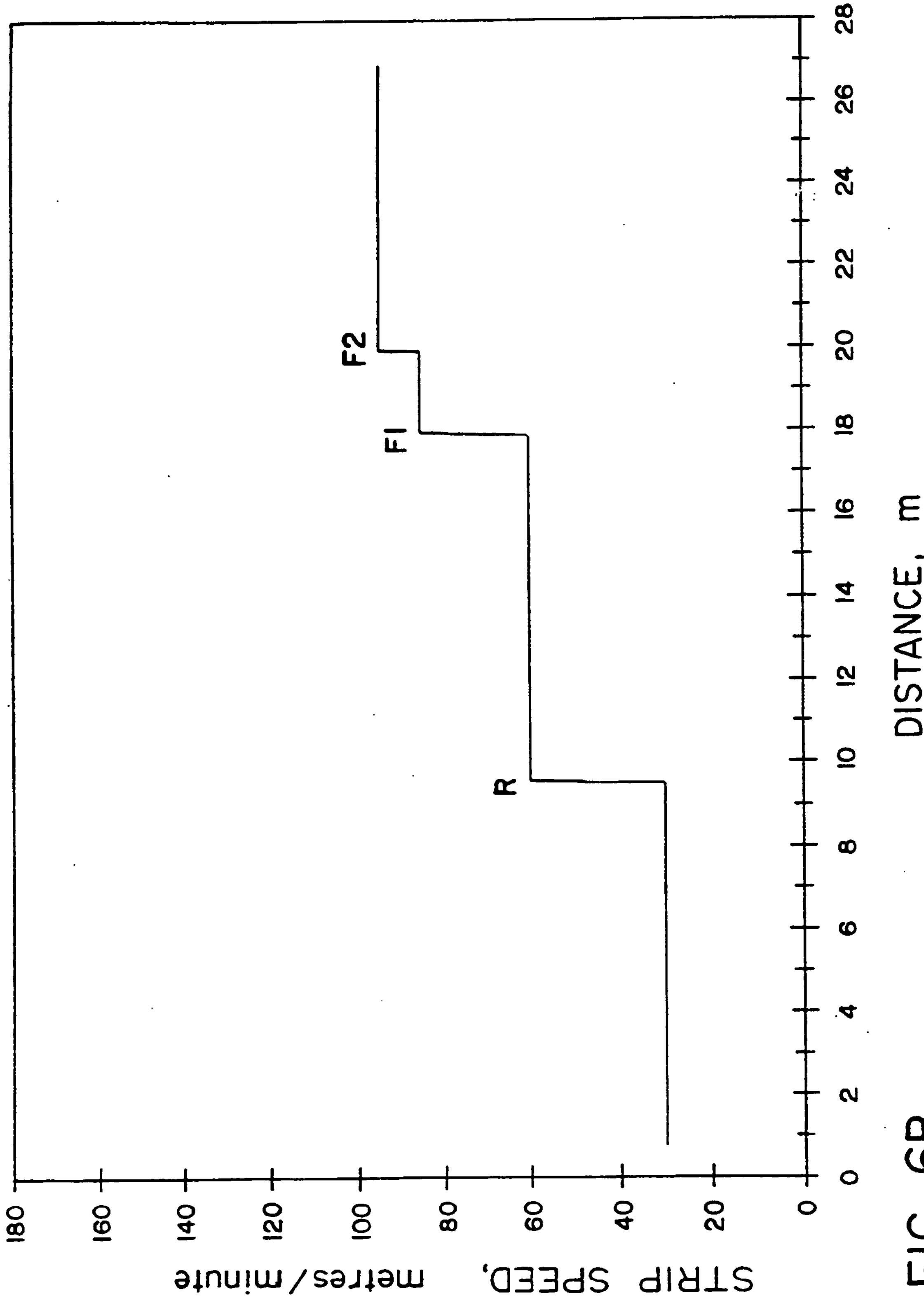
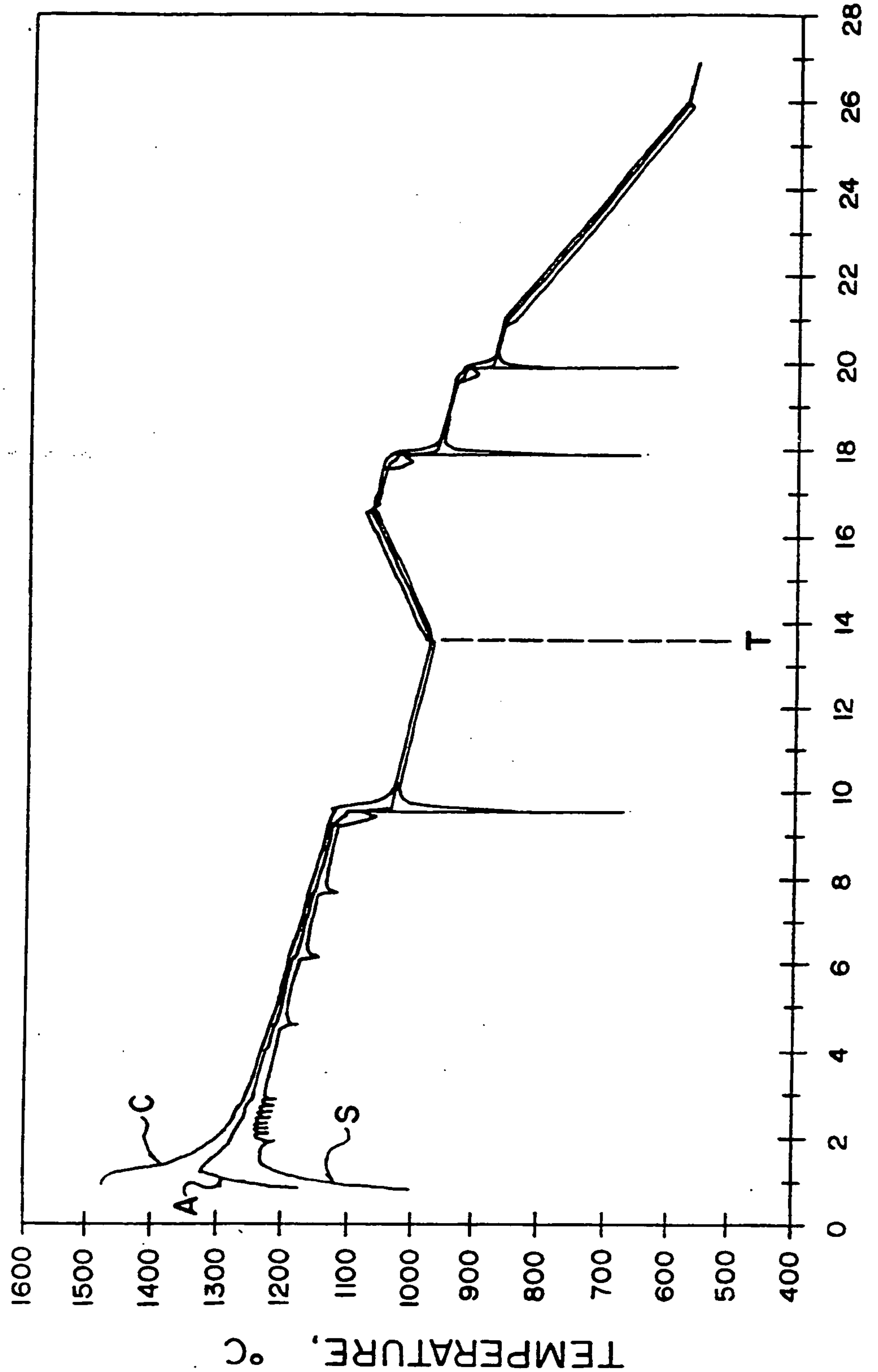


FIG. 6B

SUBSTITUTE SHEET


TEMPERATURE, °C
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1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
DISTANCE, m
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6
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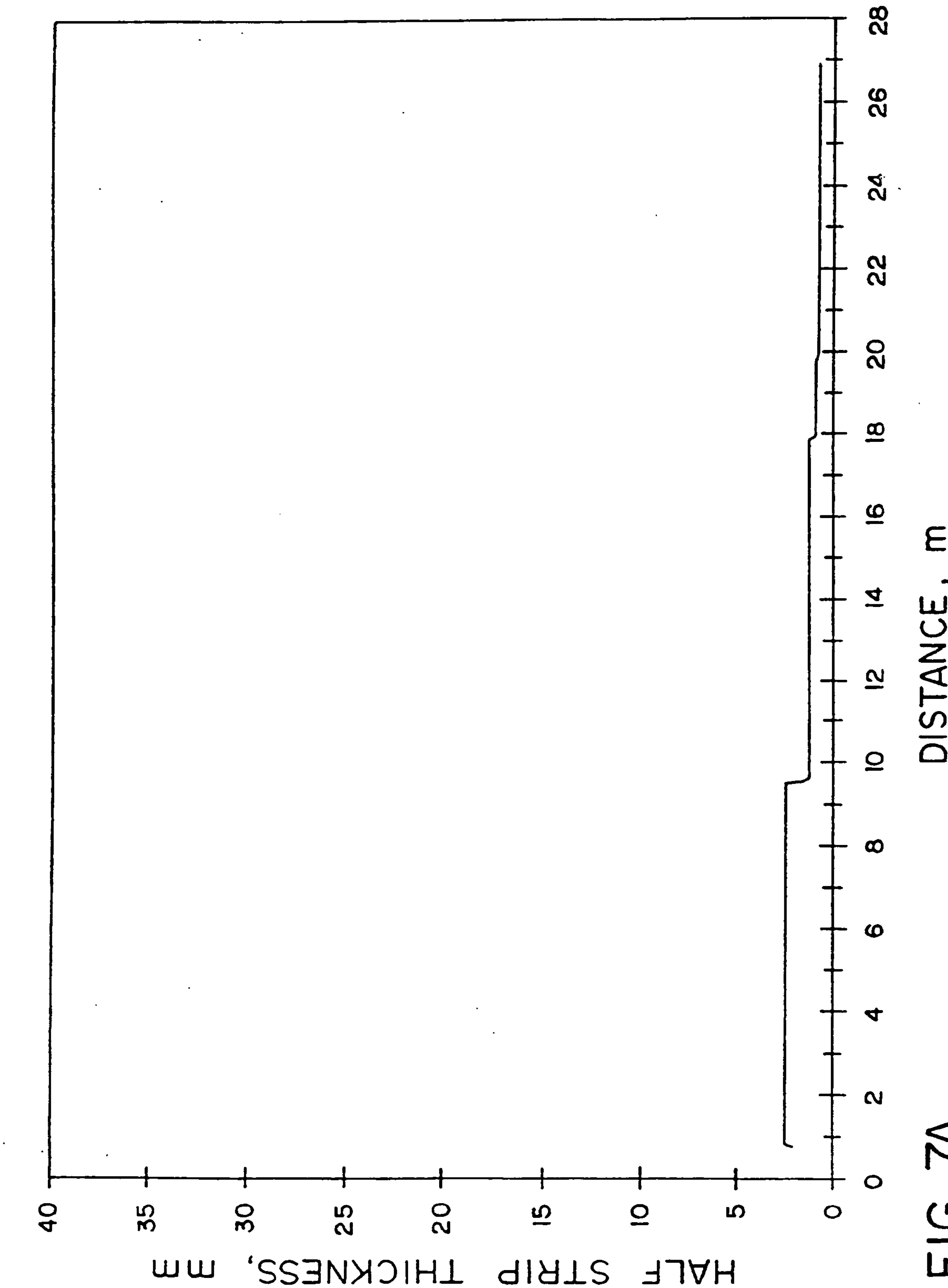
10
12
14
16
18
20
22
24
26
28
C
A
S
T

FIG. 6C


HALF STRIP THICKNESS, mm
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35
30
25
20
15
10
5
0
DISTANCE, m
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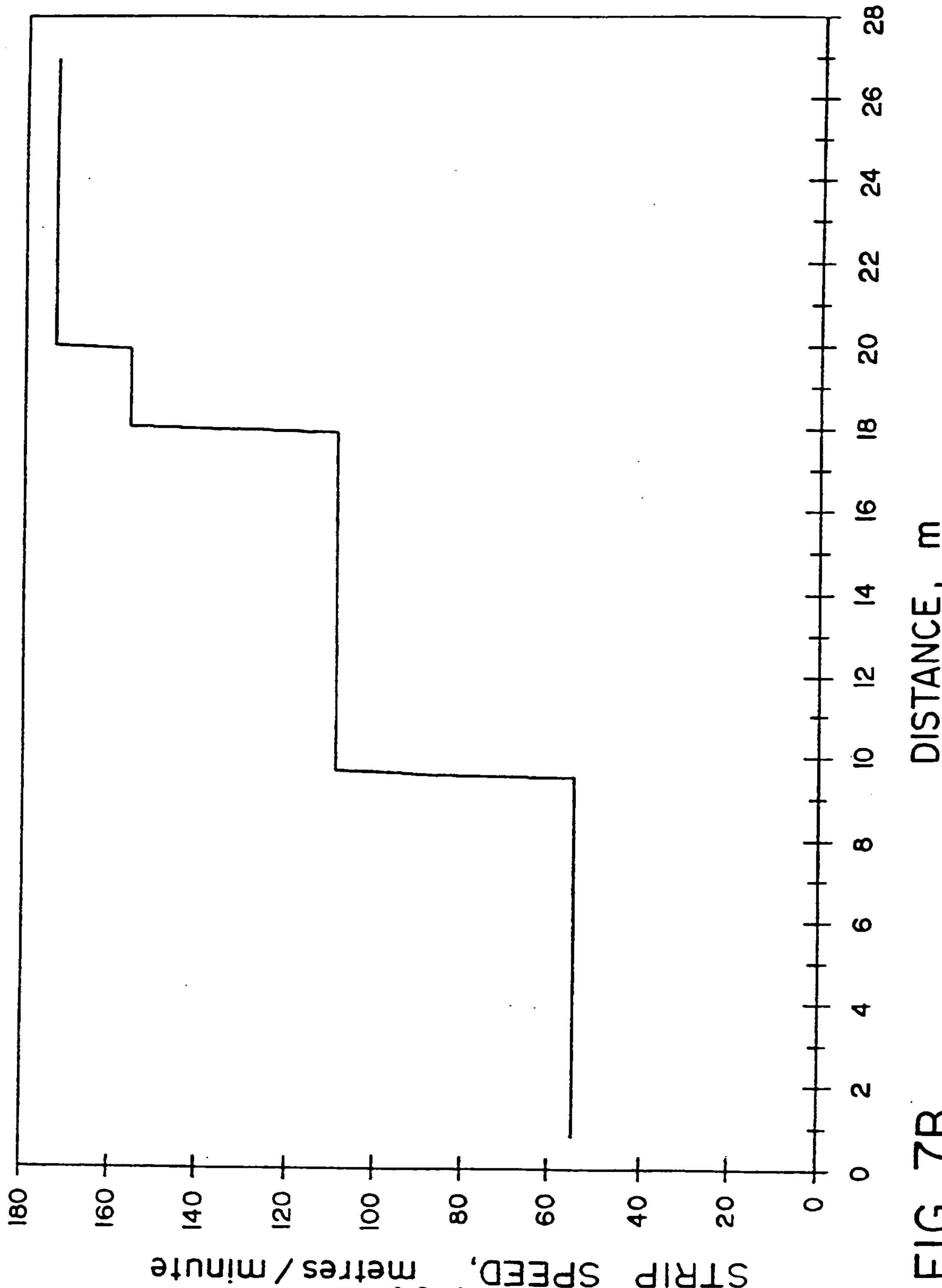
2
4
6
8
10
12
14
16
18
20
22
24
26
28

FIG. 7A


STRIP SPEED, metres / minute
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20
40
60
80
100
120
140
160
180
DISTANCE, m
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4
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8
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12
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20
22
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26
28

FIG. 7B

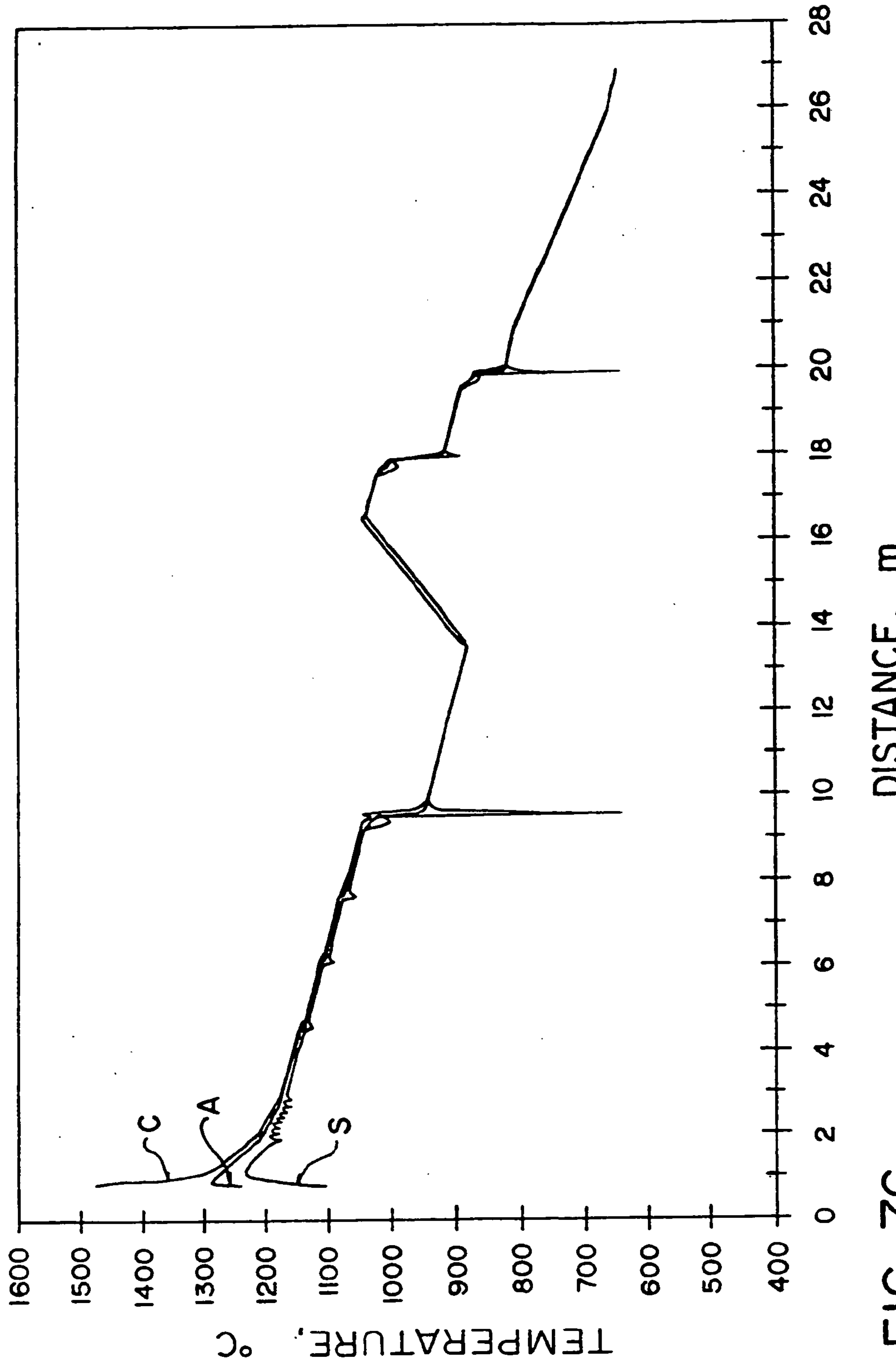

FIG. 7C

SUBSTITUTE SHEET

INTERNATIONAL SEARCH REPORT

Internal Application No
PCT/CA 95/00403

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B22D11/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B22D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP,A,0 371 281 (SMS SCHLOEMANN-SIEMAG AKTIENGESELLSCHAFT) 6 June 1990 see the whole document & US,A,5 065 811 (SCHOLZ HEINRICH ET AL) 19 November 1991 cited in the application ---	1,2,32, 42,49
Y	PATENT ABSTRACTS OF JAPAN vol. 12 no. 45 (M-667) [2892] ,10 February 1988 & JP,A,62 197246 (KOBE STEEL LTD) 31 August 1987, see abstract ---	1,2,32, 42,49
A	EP,A,0 384 151 (SMS SCHLOEMANN-SIEMAG AKTIENGESELLSCHAFT) 29 August 1990 see claims; figure -----	1,32,42, 49

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 October 1995	27. 10. 95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	WOUDENBERG, S

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 95/00403

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-371281	06-06-90	DE-A-	3839954	31-05-90
		JP-A-	2197358	03-08-90
		US-A-	5065811	19-11-91
EP-A-384151	29-08-90	DE-A-	3904989	23-08-90

Form PCT/ISA/210 (patent family annex) (July 1992)